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AN
ELEMENTARY HANDBOOK
ON
POTABLE WATER.

BY

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"He who learns the rules of wisdom without conforming to them in his life, is like a man who labored in his fields but did not sow."—SAADI.

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PREFACE.



As an analytical and consulting chemist, the author of this handbook is frequently called upon to give information on the subject of water in its relations to disease. Two bulletins from his pen on this subject have already been issued by the Iowa State Board of Health, for the benefit of the public; and from the favor with which they have been received, he has been induced to prepare the present treatise, designed especially for the use of physicians, sanitarians, and chemists. It is hoped that the subject is presented in a sufficiently interesting manner to be worthy of their study, and that the facts are expressed in scientific language capable of being easily understood by every intelligent person.

The impurities in drinking-water that are oftenest the cause of disease and death are discussed here. The natural and artificial processes of removing them from water are also given due consideration. But all methods of analysis are avoided, except some of the elementary qualitative tests given in the appendix. A

consideration of the quantitative methods for the chemical, microscopical, and biological examination of water belongs to a special treatise, which the author expects in time to offer as a companion to the present volume.

From an experience gained in the analysis and study of nearly one thousand water supplies, the writer has arrived at the conclusions here recorded. But he has also been greatly aided by the investigations and writings of others, which have appeared in so many publications that it would be useless to attempt to name them. The facts are in reality the common property of the advanced thinkers and writers in this field of science.

The author is under special obligations to the following named gentlemen who have directly aided him in preparing this book: Dr. Charles Smart, Washington, D. C.; Dr. Robert Bartholow, Philadelphia, Pa.; Professor A. R. Leeds, Hoboken, N. J.; Mr. G. W. Rafter, Rochester, N. Y.; Professor S. A. Norton, Columbus, O.; Dr. J. F. Kennedy, Des Moines, Ia.; and Professor David O'Brine, Fort Collins, Colo. He is also greatly indebted to Professor R. W. Douthat, late of Missouri University; Professor L. S. Bottenfield, of Drake University; and Mr. L. F. Andrews, of the Iowa State Board of Health, for carefully reading and correcting the proof sheets.

DRAKE UNIVERSITY, Des Moines, Iowa,
April 27, 1891.

TABLE OF CONTENTS.

CHAPTER	—♦♦—	PAGES
I. PURE WATER		7-12
II. INORGANIC CONSTITUENTS		13-21
III. VEGETABLE CONSTITUENTS		22-30
IV. ANIMAL CONSTITUENTS		31-40
V. MICRO-ORGANISMS		41-52
VI. WATER SUPPLIES		53-67
VII. NATURAL PURIFICATION		68-77
VIII. ARTIFICIAL PURIFICATION		78-95
IX. SYSTEMS FOR CENTRAL FILTRATION		96-108
APPENDIX		109-118

In Preparation.

AN
ELEMENTARY HANDBOOK
ON
WATER ANALYSIS.

By FLOYD DAVIS, Ph.D.

This is designed as a text-book and laboratory guide. It will contain a full description of the chemical, microscopical, and biological methods of analysis of water for sanitary and technical purposes.

POTABLE WATER.



CHAPTER I.

PURE WATER.

WATER is a chemical compound of hydrogen and oxygen, and is widely diffused in nature. As a solid, it exists as snow and ice; as a liquid, it constitutes streams, lakes, and seas, and in a state of minute subdivision, mist and clouds; while as a colorless vapor, it is always a constituent of the air. Natural waters are always impregnated with foreign constituents, which give to them their varying properties; and in the examination of water for sanitary and technical purposes, the water is analyzed to determine these constituents.

The palatability of water depends mostly upon its absorbed gases, which are principally oxygen, nitrogen, carbonic anhydride, and hydrogen sulphide. These gases give to the water not only an agreeable taste, but a sparkling brilliancy. The high degree of palatability and sparkle of spring-water is due mainly to its carbonic anhydride. Distilled water in its crystalline purity, or water deprived even of its gases by boiling, is insipid or "flat"; but by aeration and acidification it regains palatability. Water must be more or less im-

pregnated with gases before it is suitable even to the dietetic needs of man; for when water deprived of its gases is used for purposes of experiment, it is found to be prejudicial to health, as the stomach can neither gratefully receive nor advantageously appropriate it.¹

The palatability of water is increased also by the presence of certain salts of the alkalies. In situations where distilled water is used for drinking, as on board of ships on long ocean voyages, mineral salts are sometimes added to the water to contribute taste and the needed piquancy.² Mineral waters are now used in all civilized countries, not so much perhaps for their therapeutic properties, as for their "bouquet," or taste. Taste for mineral waters frequently becomes a matter of education, and in every city there are many persons who use other than the natural water of the vicinity to gratify their palate. But some mineral salts, like those of iron, render water containing them unpalatable to many persons; and water that has stood for some time in iron service pipes generally has a disagreeable, chalybeate taste, due to the proto-salts of iron derived from the pipes.

Researches in etiology have shown that the health of an individual, or of a community, depends largely upon the purity of the water supply. Purity here means freedom from deleterious constituents. The terms *normal* and *abnormal*, when applied to water, refer only to mineral constituents, while the terms *pure* and *impure* refer to injurious mineral as well as to organic constit-

¹ *Van Nostrand's Engineering Magazine*, December, 1872, p. 593.

² *Contaminations of Drinking-Water*, Norton, p. 3.

uents. The salts found in all normal or wholesome natural waters are found in abnormal waters, only in much greater quantity; and as some abnormal waters are injurious to health, they may be rightly called *impure*. Organic matter is also a constituent of all natural waters. Hence, pure and impure, as well as normal and abnormal, waters are distinguished only by the amount of certain constituents common to all. And it should be further stated that a water which is wholesome for some persons may be unwholesome for others, depending largely upon the condition of the system and the nature of the mineral salts in the water.

All sanitary authorities agree that the most dangerous constituents in water are the products of decomposition of organic matter, and the germs that feast upon them. It is therefore evident that a drinking-water should be practically free from organic constituents, especially if they are undergoing decomposition; and chemists uniformly condemn all waters that are contaminated with sewage. The contamination of water is shown by chemical and microscopical analyses, and by examinations of the sources of supply.

From a sanitary standpoint, *pure water* may be defined as water that is unobjectionable for general domestic use, and especially that which may be used with perfect safety for drinking.

Some waters are so unpotable that the appetite does not demand the amount required for the normal functions of the body. Such waters not only lessen bodily vigor and thus frequently produce disease, but an insufficient supply of any water to the system is manifested by great pain, relaxation of muscular strength and men-

tal vigor, and diminution in the elimination of pulmonary carbonic anhydride and bodily excretions. So, when we consider that about seventy¹ per cent of the human body is water, which is being constantly eliminated, the need of maintaining a copious supply of pure water becomes apparent ; but an abundance of water is no more necessary to the support of life than is its purity to the continuity of health. People may habitually drink impure water and still live, but its continued use unquestionably affects the human system, and tends to the degeneration of the race. Experience shows that water even slightly impure may be productive of a host of ailments for which the sufferer finds no apparent cause ; for the results are often so slow and gradual as to evade ordinary observation, and the evil is borne with the indifference or apathy of custom. Until recently, it was only when striking and violent effects were produced that public attention was arrested. But so much attention is now being given to public and private water-supplies, and so many investigations are being made by competent men, that the use of impure drinking-water is a fault rather than a misfortune, and arises more from carelessness and ignorance than from necessity. Diseases are now seldom produced by the agency of drinking-water where proper vigilance would not avoid them. Scientific investigation also reveals the fact that as a community is supplied with pure water, there is not only a decrease in the disease and death-rate, but often a most surprisingly rapid increase in thrift, morality, and degree of civilization.

¹ *Human Physiology*, Dalton, seventh edition, p. 36.

One of the functions¹ of water in the system is to cleanse the blood by dissolving the waste products that enter into it from the body, so they may be eliminated by the kidneys. Water can retain in solution only a certain amount of solids; and if it is already charged with salts when it enters the system, its capacity for dissolving and removing the waste material from the circulation is impaired. This adds extra work to the kidneys; and if already diseased, they are often incapable of performing satisfactorily the work required of them.

Aerated distilled water is the nearest perfect universal drinking-water, as it is wholesome for all classes of drinkers, and especially desirable for those afflicted with renal and bladder diseases. It acts upon the kidneys as a powerful therapeutic agent in the solution and removal of the waste products of the body. Of the importance to such persons of a drinking-water free from salts, Professor Charles Mayr² says: "Those who have never drunk pure water do not realize what an effect such water has upon the kidneys; its effect is better than that of acetates, nitrates, opiates, or alcohol, and for people with a tendency to kidney diseases or dropsy there is no better drug than pure water. Of the thousands of chemical compounds and waste products found in the human system, many require pure water for their solution and elimination; and water so overloaded with salts as average well-water is will not work satisfactorily."

¹ For a consideration of the functions of water in the system, see *Food*, Smith, p. 269.

² Report of New Jersey State Board of Health, 1887, p. 338.

It is not chemically pure water, however, that is needed for the renovation of *healthy* systems ; for such water does not exist in nature, and the small amount of mineral salts found ordinarily in drinking-water is in no way prejudicial to it. As chemically pure water contains nothing injurious to the system, it likewise contains no foreign beneficial constituents ; and, for healthy persons, such water is no more wholesome than that which contains some salts of the alkalies. The human system ordinarily requires mild cathartics and other mineral salts for the continuity of health. These, in part, may be furnished to the system as the mineral constituents of potable water, and a water that contains a small amount of them cannot, from a sanitary standpoint, be considered impure.¹ The wholesomeness of water for healthy persons is, therefore, increased by the presence of certain mineral salts² in solution, which act as laxatives, and which are essential to the development of animal tissue.

A water that is used constantly by healthy persons for domestic purposes, should have the following qualities :—

1. It should be free from disagreeable odor and taste.
2. It should at all seasons of the year be well aerated, and uniform in temperature.
3. It may contain a small quantity of mineral matter in solution, but should be free from poisonous salts.
4. It should be free from suspended mineral and dead organic matter, and should contain only such living organisms as are purifying agents.

¹ *Food*, Smith, p. 271.

² *Water Supply*, Nichols, pp. 17-18.

CHAPTER II.

INORGANIC CONSTITUENTS.

WATER is the nearest to a universal solvent in nature, and as it passes into the earth, charged with atmospheric gases, it dissolves many salts. When the water reappears again on the surface in springs, and flows away in streams, it is often heavily laden with mineral constituents; but the streams and lakes in granite regions are very nearly pure. The oceans and inland seas are the final reservoirs of flowing water, and they are saline from the concentration of their mineral matter, through evaporation. Sea-water contains about two thousand grains of total solids per gallon, while the waters of the Great Salt Lake and the Dead Sea contain about twelve thousand grains.¹

Only certain mineral salts are beneficial to health; some are deleterious; and a water that contains too large an amount of *any* mineral constituent should be avoided for drinking, as it is liable to produce derangements in the alimentary canal. The health of the people depends more upon the organic purity of their drinking-water than upon the absence of an excessive amount of inorganic salts in it; for it generally happens in cities where the waters contain a considerable amount of mineral salts, but are organically pure, that health is

¹ *Manual of Mineralogy and Petrography*, Dana, seventh edition, p. 252.

good and longevity great.¹ The agencies affecting the health of towns are so many and so powerful that a few grains more or less of mineral salts in the drinking-water can by no means have a directing influence on the health of the people.

The amount of mineral salts admissible in drinking-water depends largely upon their nature and upon the health of the drinker; for a water containing more than seven² grains of some salts per gallon is said to be injurious to many persons, although such water, from a sanitary standpoint, is ordinarily considered pure. Drinking-water used by healthy persons may have a much greater degree of mineralization than this. "With regard to the total quantity of impurities admissible in good drinking-water, the Sanitary Congress which met at Brussels decided that water containing more than thirty-five grains of impurity in one gallon is not wholesome, and that there should not be much more than one grain of organic matter."³

When the water is used for culinary purposes, the kind of mineral salts is often more important than their quantity. For on the one hand it is found that a water containing five or six grains of calcium or magnesium oxide per gallon is unfit for cooking leguminous vege-

¹ From an examination of the water supplies of sixty-five English and Scotch cities and towns, Dr. H. Letherby, an eminent English chemist and sanitarian, concluded, however, that the rate of mortality was in some cases in an inverse ratio of the amount of mineral salts in the drinking-water. While Dr. Letherby's observations were unquestionably correct, it is not admitted by leading sanitarians that the mineral salts of these waters were the important factors in promoting the health of the people.

² *Practical Hygiene*, Parkes, seventh edition, p. 56.

³ Report of American Public Health Association, Vol. I., p. 538.

tables; while on the other hand it is a great advantage in making tea and coffee to use water of about five degrees of hardness. Water containing sodium carbonate, when used for cooking farinaceous articles of food, gives to them a light golden color, owing to the action of sodium carbonate on starch.¹ Such water should not be used in preparing a solution of starch for the laundry, on account of the color which such a solution will impart to the goods.

When the amount of mineral constituents becomes so excessive as to give to the water decided medicinal properties, the water is *abnormal*, and is styled *mineral*. Mineral waters are classified according to the principal substance in solution. Thus a chalybeate water has in solution an excess of an iron salt, usually carbonate or sulphate, and, upon standing exposed to the air, generally deposits a yellowish brown precipitate of hydrated ferric oxide;² a saline water has in solution an excess of some salt, like sodium chloride, or sodium and magnesium sulphates; a carbonated or effervescent water has carbonic anhydride, and an acidulous water has sometimes hydrochloric and sulphuric acids in excess; while a sulphur or hepatic water contains an excess of hydrogen sulphide. Upon standing, hepatic waters become turbid and deposit sulphur. Since many salts have a characteristic taste, the nature of mineral waters can often be determined by the sense of taste alone.

¹ *Water Supply*, Nichols, p. 137.

² It is frequently noticed that some surface waters upon standing become turbid and deposit a yellowish brown sediment. This is generally due to ferrous carbonate, or some organic proto-salt of iron, in solution, which on exposure to the air becomes oxidized and precipitates as hydrated ferric oxide.

Saline waters, when used occasionally and moderately for drinking, are generally beneficial to health, owing, in part, to the cathartic action of the sulphates and phosphates of the alkalies and magnesium, which are usually found in such waters ; but their excessive use, or the prolonged use of waters containing too much salts in solution, should be avoided. It should be remembered that ordinary drinking-water, when taken into the system in large quantities, acts as a cathartic upon the average drinker ; and when it does not, a small quantity of common salt will accomplish this effect. Hot saline waters, when frequently used for bathing, also often afford relief to persons afflicted with inflammatory rheumatism. Carbonated waters are not only highly palatable, but they are beneficial to persons suffering from dyspepsia. But waters containing much hydrogen sulphide are not really wholesome, as they will produce diarrhœa,¹ especially if organic matter be present ; but in small quantity, hydrogen sulphide is in no way injurious to health.

Many of the mineral waters now used are made *artificially*. But when their constituents exactly imitate those of a *natural* mineral water, no method of analysis can distinguish between them, and no substantial reasons can be assigned why one is superior to the other.² Some of these waters contain enough salts to enable them to act therapeutically, but many of them are so weak that it is doubtful if they have any medicinal virtue. But as mineral waters are generally quite palatable, their

¹ *Practical Hygiene*, Parkes, seventh edition, p. 58.

² See *The Mineral Water Controversy*, Schultz.

use is constantly growing, and there is scarcely a drug store in a populous city without its patrons who obtain much of their drinking-water from the natural and artificial supplies kept for sale.

Some salts are productive of indigestion, and in many cases constipation and visceral obstruction are induced by the use of mineral waters. Chalybeate waters not infrequently induce in the drinker headache, indigestion, and dyspepsia. A drinking-water should not contain more than one-fifth¹ of a grain of iron per gallon. Dyspepsia is also frequently produced by water containing calcium and magnesium salts. Calcium and magnesium chlorides and sulphates, in excess, will also produce chronic diarrhœa, and it is generally true that a change from soft to hard water will induce diarrhœa in susceptible persons. This effect soon passes off, and the susceptibility will, in less time than is generally supposed, change to the opposite idiosyncrasy. If the water also contains ammonium and calcium nitrates and sodium chloride in excess, and is used freely, it is sometimes the cause of dysentery. Goitre, so frequently found among the inhabitants of some of the valleys of Switzerland, is ascribed to the excessive permanent hardening constituents of the water.

The normal carbonates of the alkaline earths, magnesium and iron, are practically insoluble in chemically pure water.² But the bicarbonates of these metals,

¹ *Water Analysis*, Wanklyn and Chapman, sixth edition, p. 61.

² "About one grain of calcium carbonate to the gallon is usually stated to be the proportion dissolved; but it has been pointed out lately by Allen that this is an under-statement, since solutions have been obtained containing twice this amount." — *Examination of Water for Sanitary and Technical Purposes*, Leffmann and Beam, p. 93.

which are readily soluble, are formed by the union of carbonic anhydride and water, with the normal carbonates, and there is scarcely a natural water which does not contain a small amount of them. It is claimed by some eminent authorities that small quantities of these bicarbonates in drinking-water are beneficial to health; and the popular theory that hard water conduces to the formation of urinary calculi,¹ has, in some cases, been disproved by surgical experience. Thus it has been observed that the majority of cases of this disorder in Philadelphia² are located in the Kensington district, which is supplied with softer water than the other portions of the city.

But hard water sometimes unquestionably promotes calculus secretions; for whatever causes a retention of urine in the bladder, a retardation in the elimination of the waste products from the blood, or a waste of nerve tissue, may give rise to them. Owing to the inability of hard water to remove readily the waste products from the blood, they are retarded, the kidneys are overworked, and calculus deposits occur in very important and delicate organs, especially in the kidneys, urethra, and bladder. Through the agency of hard water, phosphorus is extracted from the system, for it is observed that persons who drink water strongly impregnated with lime furnish urine richer in phosphates than those who drink soft water only.

¹ Urinary calculi are generally composed of sodium and ammonium urates, calcium oxalate, and sodium, potassium, calcium, and magnesium phosphates. Calculi composed of urates and oxalates almost always have their origin in the kidneys, while those originating in the bladder are generally phosphatic.

² *The Principles and Practice of Surgery*, Agnew, Vol. II., p. 630.

Experience has shown that large quantities of the bicarbonates of the alkaline earths in a drinking-water are in this way sometimes injurious.¹ If in excess, they are perhaps decomposed in passing through the system, and give rise to renal and bladder difficulties, which sometimes culminate in gravel. The bicarbonates are not generally found in well-waters in excessive quantities; but the continued use of spring-water which flows from limestone rock may eventually give rise to disease, for communities which use limestone water only, are sometimes afflicted with diseases which arise from overworked kidneys.²

Another injurious property of limestone waters is their tendency to neutralize the gastric juice and to produce an alkaline reaction in the urine, which in health is always acid. These bicarbonates are the cause of temporary hardness in water, and can be removed by boiling, as by this process bicarbonates are decomposed into normal carbonates, which precipitate, and the carbonic anhydride and water escape. Water is rendered permanently "hard" usually by the solution of the sulphates of calcium, magnesium, and iron. Nearly all

¹ *Water and Water Supply*, Corfield, pp. 11-12.

² "Stone in the bladder is much more frequent in certain localities than in others. In the United States, it is most common in Kentucky, Ohio, Tennessee, and Virginia. In the New England States it is exceedingly rare. The same inequality of distribution as regards locality has been noticed in other parts of the world. It is probable that climatic and other influences determine, in some measure, these topographical differences; but it is well known that vesical calculi are met with most frequently in lime districts, and especially where the lime rock is soft and soluble, and the water constantly holds a large amount in solution, as is the case in the States of Kentucky and Tennessee." — *The Principles and Practice of Surgery*, Hamilton, third edition, p. 831.

natural waters contain some of the carbonates or sulphates of these elements, but they are not commonly designated as "hard" waters unless they have six degrees of hardness, Clark's scale.¹

The compounds of some elements, like arsenic, antimony, barium, chromium, zinc, copper, and lead, are dangerous poisons, and water containing even traces of them should always be avoided, unless the water is used as a tonic.

Lead is a cumulative poison, but there is a great difference in the susceptibility of different persons to its action. "It is thought that as little as one-fortieth of a grain to the gallon has caused sickness, but one-tenth of a grain is usually regarded as an outside limit."² Lead poisoning is not infrequent in some cities where the water for domestic use passes through lead pipes. Aerated water tends to dissolve lead, forming a hydrate. In presence of carbonic anhydride in excess this hydrate is converted into a slightly soluble bicarbonate of lead. Nitrates and chlorides in the water readily dissolve lead, but sulphates and normal carbonates tend to form insoluble compounds on the inner surface of the pipes, which prevent further action of the oxygen upon the lead. Lead pipes should, therefore, only be used in conveying drinking-water that contains sulphates or normal carbonates in solution.³

¹ A degree on Clark's scale is one grain of calcium carbonate, or its equivalent, per gallon of water. In water analysis it is customary to report the results in parts per 1,000,000 of water. To change from parts per 1,000,000 to grains per gallon, multiply the results by 58,318 and divide by 1,000,000.

² *Water Supply*, Nichols, p. 213.

³ *Treatise on Poisons*, Taylor, third American edition, pp. 418-424.

Dr. Kirker¹ has recently observed that the power of certain samples of water to dissolve lead is directly proportional to the number of micro-organisms that the samples respectively contain. It is probable that the lead is here dissolved by organic acids, which are the results of decomposition produced by *Bacteria*.

Galvanized iron pipes are also liable to render dangerous the water that passes through them; for such water frequently, if not invariably, contains salts of zinc, but the amount is generally very small.² Zinc chloride is sometimes used by tanners in soldering tin cans, and goods preserved in such cans are sometimes poisoned by the zinc salts contained in them.³

Potable water often contains suspended mineral matter, such as sand and clay. These substances act as mechanical irritants, and it is believed that an excessive turbidity, caused by them, is productive of intestinal difficulties, indigestion, dyspepsia, and diarrhœa. They may collect in certain parts of the alimentary canal, but they cannot in any way enter into the circulation. Foreign solid bodies that have lodged in the alimentary canal have in some cases produced fatal results, by exciting inflammation, ulceration, or gangrene.⁴ The character of the suspended matter in water can be fully determined only by means of the microscope.

¹ *The Sanitary Era*, March, 1890, p. 107.

² For a consideration of the effects of zinc salts on the system, see Dr. Boardman's paper on this subject in Report of Massachusetts State Board of Health, 1874; also, *Treatise on Poisons*, Taylor, third American edition, pp. 459-464.

³ *Chemical News*, June 5, 1885, p. 268.

⁴ *Treatise on Poisons*, Taylor, third American edition, p. 135.

CHAPTER III.

VEGETABLE CONSTITUENTS.

THE turbidity of water is sometimes produced by decomposing organic matter, which renders the water unwholesome. No turbid water should be used for drinking. With the exception of pathogenic germs, the products of decomposition of organic matter are indirectly the most dangerous of all the impurities in water; but the products of animal decay are more dangerous than those of vegetable decay.

Although the products of vegetable decay *indirectly* produce malarious diseases, they are not in themselves known to be especially injurious to the human system; they probably furnish a pabulum in which certain disease germs flourish, for the malarious influence is attributed by medical science to the agency of a micro-organism (*Bacillus malarie* of Klebs and Tommasi-Crudeli). Waters containing the products of organic decay develop a remarkable growth of germ life, and it is the opinion of competent judges that such waters, if used for a considerable length of time, are injurious to health.

Germs are frequently conveyed to the system by the air, but the most dangerous cases of malaria are caused by polluted water, which seems to be a more concentrated and dangerous poison than malarious air. And

in the production of remittent fever¹ by malarious surface water it is noticeable that the disease is always of a more aggravated type than when caused by exhalations from miasmatic soil. Water in which there is a copious decay of aquatic plants is said to produce intestinal worms; and the decay of certain aquatic plants in a water supply is sometimes accompanied by an alarming mortality of fish.²

Many cases are on record from the American Civil War, in which the use of surface water, impregnated with the débris of plants, like decomposing cellular tissue and chlorophyl, produced diarrhœa; but when such water was filtered, the disease abated.³ Even decaying wood, like pump-stocks and storage-tanks, contaminates water and often produces harmful results, and saw-dust⁴ in water is a fruitful source of malarious fever. But in the decay of the woody tissue the soluble products are extracted and carried away in the water, while the remainder of the tissue becomes humified as in the case of peat. These thoroughly humified products remain in the soil and do not seem to injure water, except in giving it a brownish color and an earthy taste. It is owing to this fact, that by draining their swamps and cultivating the soil, rural communities have often freed themselves from much sickness of a dangerous malarious character.

Undecomposing vegetable matter, suspended in water,

¹ *Water Supply of U. S. Capitol*, 49th Congress, 1st Session, Ex. Doc. No. 154, pp. 8-9.

² *On the Micro-Organisms in Hemlock Water*, Rafter, p. 16.

³ *Practical Hygiene*, Parkes, seventh edition, p. 57.

⁴ Report of Michigan State Board of Health, 1882, p. 155.

is generally harmless. Most of the commonly occurring plants, shrubs, and trees do not secrete poisonous compounds, and during the period of growth these plants cannot be considered injurious to the human system; only those plants that produce vegetable poisons are dangerous while living. This is especially true of plants that inhabit water supplies, for examinations of aquaria show that many growing aquatic plants are harmless, and it is doubtful if any living species are injurious to the water in which they grow. Cryptogams, known as *Algæ*, grow in nearly all water supplies exposed to air and sunlight; and there are upward of fifteen hundred species of fresh-water *Algæ* known to cryptogamic botanists. Many of these species are purifying agents, and are found in the unfiltered water supplies of our cities. They are, however, easily removed by the ordinary processes of filtration.

Algæ are generally of a greenish color in water, but when dried many species are grayish or nearly colorless. Water containing the products of their decomposition is sometimes very unpalatable from a disagreeable odor and taste given to it. These unpleasant features are ascribed to the dead and not to the living plants, and are not usually prejudicial to health. When under the excessive heat of summer, *Algæ*, collected in masses in ponds or streams, decay rapidly, and evolve a disagreeable odor. When they are collected in the "dead ends" of city water mains, and then decay, the water drawn from the pipes has also a disagreeable odor, but there is scarcely any odor from water drawn from service pipes in which the water is constantly flowing.

The majority of *Algæ* prefer sunlight and the purest natural waters ; but some of them remain under shaded banks and driftwood accumulations ; some inhabit sluggish streams, ponds, and lakes, and are indicative of organic pollution ; while others live only in waters containing certain mineral salts in solution. Thus the *Flagillata* are generally found in water containing decaying infusions of vegetable and animal matter, and they have been detected even in the dejections of cholera and typhoid fever patients. *Beggiatoa*, and perhaps *Oscillaria* and *Ulothrix*, are found only in stagnant waters, or in waters containing sulphur in some form, but free from iron.¹ *Batrachosperma* inhabit rapidly running limestone waters, while some species of *Inactis* are found only in silicious waters. *Cladophora* and *Vaucheria* are generally found only in saline waters, and it is doubtful if the marine forms of these *Algæ* can live in water containing no sodium chloride.²

Algæ that do the most harm to water usually appear as greenish specks or minute threads, giving a green or yellowish green tinge to large bodies of it. They increase with great rapidity under circumstances favorable to their growth, and their decomposition gives an offensive odor to the air in the vicinity, and sometimes an objectionable taste to the water in which they decay. The disagreeable odors and tastes, known as "pig-pen," "fishy," "musty," "cucumber," "woody," and some others, have been traced to decomposing *Algæ*.

¹ *Water Analysis*, McDonald, p. 25.

² *On the Fresh Water Algæ and their Relation to the Purity of Public Water Supplies*, Rafter, pp. 3-4.

Recent investigations¹ show that several families of *Algæ* are capable of producing these objectionable odors and tastes in water, and that these products are especially rancid when produced by certain of the grass-green varieties; but the power of *Algæ* to produce odor and taste seems entirely independent of color. This is shown by the fact that *Volvox* and *Cladophora* are grass-green, *Nostoc* and *Clathrocystis* are bluish green, while *Crenothrix* and *Beggiatoa* are nearly colorless, and all of these may be objectionable in a water supply.

Nostoc, which sometimes develops rapidly in wet places after a rain, is a frequent contamination of water; and it is of especial interest in this connection as being the chief source of the unpleasant "pig-pen" odor of water supplies. It has been noticed that *Anabaena*, *Sphærozyga*, *Crenothrix*, *Lyngbya*, and *Oscillaria* are at times also the cause of an unpleasant odor and taste of the "pig-pen" character. All of these *Algæ* belong to the family *Nostocaceæ*. Two other *Algæ*, members of the family *Chroococcaceæ*, are also known sometimes to produce a "pig-pen" odor and taste in water.

The water supplies of some of the eastern cities have at times a decidedly "fish-like" odor and taste. Professor Lattimore² as early as 1876 suggested that this odor and taste in the Rochester water were due to the presence of an *Alga* perhaps in a state of decomposition. These unpleasant properties of this water were in 1888 shown to be due to the decomposition of the

¹ *On the Fresh Water Algæ and their Relation to the Purity of Public Water Supplies*, Rafter, p. 2.

² *Annual Report of Executive Board of Rochester, N.Y.*, 1876, p. 116.

unicellular *Alga*, *Volvox globator*.¹ This *Alga* appears as a nearly transparent sphere, from one-fiftieth to one-eightieth of an inch in diameter, and is studded on its inner surface with symmetrical, hexagonal groups of dark green points.

Power to produce odor and taste is not a characteristic of any class of *Algæ*, but depends upon the capacity of certain of these organisms for secreting starch, oil, or sulphur, and upon the vigor with which they develop. The odor and taste of water are sometimes of short duration, but they generally recur in the same water supply year after year, when it reaches the temperature favorable for the development and decay of each species of contaminating *Algæ*. *Algæ* sometimes suddenly appear in water where they have not been known for years, and they sometimes disappear as suddenly as they came. The intensity of the odor and taste of a water supply may be generally taken as a measure of the rapidity of decomposition of *Algæ* present at any given time, and it is therefore a measure of the cryptogamic growth. Hydrogen sulphide in water, however, may be produced in other ways.

Some waters which come from clay soil have so strong an odor of hydrogen sulphide and "sulphuretted hydrocarbons" as to be undrinkable, and yet the amount of organic matter in them will not often warrant their condemnation. These gases are probably produced in the decomposition and reduction of sulphates by decomposing organic matter,² and by living *Bacteria* and low

¹ On *Volvox Globator* as the Cause of the Fishy Taste and Odor of the Hemlock Lake Water, in 1888, Mallory, Rafter, and Line.

² *Water Supply*, Nichols, pp. 85-86.

forms of *Algæ*. Under a favorable temperature, decomposing organic matter reduces sulphates to sulphides, and from these hydrogen sulphide is liberated by the acid products of decay.

Of the *Algæ*, the genus *Beggiatoa* probably possesses the power of extracting sulphur from decomposing organic matter containing it, with the liberation of hydrogen sulphide. This genus also possesses the power of extracting sulphur from sulphates in water, appropriating a portion of the sulphur perhaps in an amorphous state into its protoplasmic cell structure, with the liberation of the remainder of the sulphur as hydrogen sulphide. The presence of hydrogen sulphide in water is, therefore, no reliable indication of organic pollution.

The waters of rivers, ponds, and lakes generally have more or less odor, taste, and color,¹ and it is not often, except in mountainous regions, that surface waters are free from these exponents. So far as an unpleasant odor and taste are concerned, they may in some cases cause gastric disturbances, and, secondarily, intestinal derangements; but further than these, the odor and taste of a water supply cannot affect public health.

To determine the odor of water, it is generally convenient to liberate the gases in a wide-mouthed, gallon bottle having a glass stopper. Place into it about one-half gallon of the sample to be tested, and shake thoroughly. Remove the stopper, immediately insert the nose, and notice the odor. Sometimes the water must be heated to liberate the odorous gases. For

¹ *The Odor and Color of Surface Waters*, Drown, Report of New England Water Works Association, March, 1888.

such cases use a Florence flask of one litre capacity. Put into it about one-half litre of the sample, cover with a watch-glass, and heat it nearly to the boiling-point. Then allow the water to cool a little, remove the watch-glass, and notice the odor. By this method of investigation, waters may be found to possess varying degrees of odor, like "very faint," "faint," "distinct," "decided," and "strong."

Pure water in thin layers is colorless, but in considerable volume it has a decidedly bluish tint, which comes from its power to absorb and transmit light. Surface waters are generally more or less colored from suspended matter, and from organic substances held in solution. The commonest color is yellowish brown. Rain-water is sometimes highly colored with vegetable matter from the roofs of buildings, but it is often a healthy drinking-water, on account of the stability of its organic matter. The chlorophyl of unicellular *Algæ* generally gives to the water in which it grows a greenish color, but green waters are not unwholesome, unless the *Algæ* are decomposing, and even then they are rendered harmless by a thorough filtration. Peat gives to water a brownish color, but analyses and long-continued use demonstrate that such water is usually wholesome. It has a laxative effect upon the systems of strangers to the locality, but the action is only temporary, and can, therefore, in no sense be injurious. Peat water is often used for drinking on long ocean voyages, on account of its power of retaining freshness.

The color of water is usually determined by examining a sample of it through a two-foot colorless glass cylinder, or a "metre tube," when it is nearly colorless,

and when considerably colored, by examining it through a "Nesslerizing tube." Standard colors for comparison are sometimes prepared by adding standardized solutions of ammonium chloride to dilute solutions of Nessler's reagent.¹

¹ *Sanitary Examinations of Water, Air, and Food*, Fox, pp. 20-24.

CHAPTER IV.

ANIMAL CONSTITUENTS.

THE lowly organized animal, like the vegetable, scavengers, are among the most important purifying agents in water, as they also assimilate the decomposition products of organic matter. All natural waters contain animal organisms, some of which, perhaps, are injurious when taken into the human system, but it is seldom that potable water becomes deleterious from the living animals in it. A large number of micro-organisms in water is, however, indicative of organic pollution.

Undecomposing animal, like undecomposing vegetable, matter, suspended in water, is also generally, if not invariably, harmless; but danger lies in the products of its decomposition. These products are always more dangerous to the human system than those from vegetation, as they are nitrogenous; and water that is contaminated with the animal accumulations of sewers, cesspools, and privies, is a loathsome and dangerous beverage. A microscopical examination of such water often reveals the presence of hair, excreta, intestinal epithelial cells, as well as the living organisms in it. Such water should be absolutely condemned for all sanitary purposes, as these impurities could come only from sewers, cesspools, and privy-vaults. The living organisms in it feast upon the products of decay. These

polluted waters are often deceptive, since they may have an agreeable taste and be highly palatable. Generally, however, they are quite offensive.

Polluted water is generally infested with *Infusoria*.¹ This is especially true of stagnant surface water, and the water from many surface wells. All true *Infusoria* are covered with cilia, by means of which they glide through the water. One of the largest and commonest of the *Infusoria* that inhabit polluted water is the *Paramecium*. This animalcule is a unicellular mass of protoplasm, in which is excavated the digestive cavity. Recent investigations in biology demonstrate that nitrogenous food is necessary for the development of *Infusorial* life in water ; but there are certain conditions not yet clearly understood, aiding, in presence of nitrogen salts and phosphates, the transformation of harmless organic matter into a favorable pabulum for the growth of micro-organisms.² Phosphates are not usually found in considerable quantity in potable water, and the presence of *Infusorial* life in water free from phosphates, is, therefore, very reliable evidence of pollution.

Cyclops and *Daphnia*, usually known as water-fleas, are the commonest genera of *Entomostraca* found in potable water. These also tend to purify water by removing the organic ingredients, and they are themselves devoured by other higher animals. Serious outbreaks of fever, diarrhoea, and dysentery have been produced by water so polluted with organic matter as to

¹ *The Animal World of Well-Waters*, Popular Science Monthly, June, 1889, pp. 251-257.

² *On the Micro-Organisms in Hemlock Water*, Rafter, p. 4.

furnish sustenance for swarms of *Entomostraca*.¹ But there is no reason to believe that the *Entomostraca* are injurious when taken into the human system. They ought not, however, to exist in water supplies, since they can be easily removed by the ordinary processes of filtration. Dr. H. C. Sorby² has shown that the number of certain of the *Entomostraca* in water may be taken as a measure of its organic pollution, for an increase in sewage is indicated by an increase in their total number, or by an alteration in the relative number of each species, or by both.

Fresh-water sponges are frequently found in the water of streams, ponds, and lakes, and they probably exist in nearly all surface waters. Under certain conditions their decay produces the "cucumber" odor and taste in water. "In 1881, a portion of the water supply of Boston, Massachusetts, was in a very bad condition. The water contained an unusual amount of organic matter and possessed a very disagreeable odor and taste. This bad condition of the water was found by Professor Remsen to be due mainly to the presence in one of the reservoirs of a large quantity of a *Spongilla*, or fresh-water sponge, in a more or less decayed condition."³ Ordinarily, sponges do no harm to water, and their presence in a water supply need not awaken alarm.

Two other forms of invertebrates may be mentioned here, although they are quite unimportant: The ciliated

¹ *On the Use of the Microscope in Determining the Sanitary Value of Potable Water*, Rafter, p. 11.

² *On the Micro-Organisms in Hemlock Water*, Rafter, p. 25.

³ *Water Supply*, Nichols, p. 80.

embryos of certain *Entosoa* are sometimes found in potable water. They are generally very active in early life, but finally lose their ciliated coverings and perish, unless they find their way into the body of some animal drinking the water. *Leeches*, in this connection, are mere curiosities, still they are sometimes accidentally swallowed in potable water. They are liable to attach themselves on the pharynx, and when once fixed they seldom fall off spontaneously. Coughing, nausea, and spitting of blood are produced by them, and repeated bleeding from the larynx produces anæmia.¹

Nearly all natural waters are supplied with more or fewer fish, the presence of which cannot be considered injurious to the waters, as they too are purifying agents. In water that is pure and aerated there can be no trouble arising from them. But a sudden discharge of some chemicals or filth into a water supply not infrequently poisons the fish or destroys them by removing the free oxygen from the water. Oftentimes there is also a remarkable growth of *Algæ* in the water, which becoming parasitic to the fish, especially in the gills, seem to destroy the fish by preventing the absorbed oxygen of the water from coming in contact with the blood. In the summer of 1889, the Iowa River, below Marshalltown, became so polluted from the refuse of the Marshalltown Glucose Works that it evolved a disagreeable odor and destroyed the fish in great numbers.² These fish were invested in a growth of *Beggiatoa alba*, which *Alga* was developed upon the sulphur pollution

¹ *Practical Hygiene*, Parkes, seventh edition, p. 78.

² Bulletin of Iowa State Board of Health, July, 1889.

in the water. It therefore seems apparent that a water which contains dead fish is unwholesome, for it either lacks aeration or is polluted. If such water is used for domestic purposes, epidemics may arise either from the original impurities in the water or from the products of decomposition of the fish. A proper supervision of a water supply will prevent any danger from this source.

Generally organic matter is easily putrescible, and water containing putrescent animal matter is liable to produce putrefactive changes in persons who drink it. The nitrogenous matter disintegrates through the agency of micro-organisms, producing in its earlier stages, *Ptomaines*, bodies which are closely allied to the vegetable alkaloids, but more susceptible of decomposition. Although the *Ptomaines* are present in very small quantity in polluted water, yet they are very active in their pathological effects, and produce harmful results when taken into the system. Indeed, it may be true that these are the real agents of all zymotic diseases. Other products of decomposition furnish a suitable pabulum for the accumulation and multiplication of germs of disease.

Many contagious and infectious zymotic diseases are produced by water polluted with decomposing animal matter, and, indeed, it is highly probable that certain diseases are seldom produced in any other way.¹ The

¹ "There is abundant proof that drinking-water has been instrumental in the spread of the following diseases: Cholera, Typhoid Fever, Dysentery, Diarrhoea, Diphtheria, Malaria, Cholera Infantum, and Cerebro-Spinal Meningitis; and in addition to these, certain low forms of fever to which no other name than Continued Fever can be given." — *Report of Brooklyn Commissioner of Health*, March 10, 1884, p. 19.

general public is slow to appreciate the terrible relation which often exists between certain infectious diseases and the filthy surroundings of many of the people subjected to them. Cholera and typhoid fever are typical filth diseases, which are communicated through the air, water, or food used ; and their fatal effects are often the results of pure ignorance, carelessness, and superstition. Impure water is now generally considered the most prolific cause of these diseases, as will be seen from the following brief considerations :—

Cholera is a zymotic disease, in which the producing poison is most easily conveyed to the system from the dejections of cholera patients. To only few of the earlier investigators did it occur that these dejections might gain entrance to the system through drinking-water ; but all the most virulent cholera epidemics of the last half century have been traced to this source, and there is no longer any doubt of their filthy cause. Under no circumstances, therefore, should a water be used in a time of cholera epidemic, without first being boiled, if in any way it has access to the impurified air and soil. The most disastrous epidemics of Asiatic cholera originate at the encampments of the ignorant and superstitious pilgrims in India, the birthplace of cholera, where thousands fall victims to its ravages at each of the gatherings.¹

We are occasionally very much alarmed at the introduction of Asiatic cholera into Europe, and its possible introduction into America, though we remain oblivious to the fatal results of typhoid fever at home. While this

¹ For a graphic description of the origin of Asiatic cholera, see Appendix.

fever is generally produced by water, recent investigations prove that it is sometimes produced also by impure air and impure food. Even milk is sometimes the agent of this disease, in which case the typhoid poison remains undestroyed in passing from the polluted water from which the cows drink, to the milk-secreting glands. Typhoid fever as generally produced is, however, above all others a filth disease, but less ravenous than cholera. In the words of a distinguished writer: "Typhoid fever is of comparatively modern growth among us; and while some attention has been bestowed upon drainage and improved modes of living, which doubtless have stamped out a terrible disease known to our forefathers as plague, we have introduced from sheer carelessness and indifference the more modern, and I was about to add, more fashionable, plague, properly designated filth disease."¹

In speaking of the transmission of typhoid fever, Sir William Jenner² says: "Indeed, I have never seen a case, removed from its place of origin, spread to the inmates of the house into which it was removed, unless there was a direct communication between the source of drinking-fluid and the bowel discharges of the patient." Many noted epidemics of typhoid fever have been traced to water supplies. One of the most noted occurred at Lausen, Switzerland, and is mentioned elsewhere. The Plymouth epidemic in the mining region of Pennsylvania is also well known. An extensive development of typhoid fever here occurred, with many deaths. A medical commission determined that a spo-

¹ Mapother's *Lectures on Public Health*, p. 444.

² *Etiology of Acute Specific Diseases*, 1875.

radic case occurred several miles above the town, and that the dejections from the patient were thrown into a stream which flowed into the water supply of Plymouth. These cases show that the dejections from a single typhoid fever patient are sufficient to poison the water supply of a whole town, and give rise to an extended outbreak of fever. It is, therefore, apparent that human faecal matter is very dangerous, as it may contain germs capable of setting up a specific form of disease. As sewage is largely made up of this kind of matter, it is a very dangerous form of pollution. Sewer gases are also productive of disease,¹ especially when the atmosphere is dry and heavy, as it then favors the accumulation of the products of decomposition and the production of germs.

In the fall of 1887 typhoid fever became epidemic in Ottawa, Minneapolis, Pittsburgh, and many other cities, and it was found on examination that in every case known to the writer, the disease was communicated through potable water. In Pittsburgh the circumstances were especially interesting. The south side of the city was supplied by the Monongahela Water Company's works, and the fever was located in districts supplied by that company. Upon chemical and microscopical examination of the water, the pollution was traced many miles above the city to a ravine into which drained the privies of houses where four typhoid fever patients had been located several weeks before.²

¹ Report of Michigan State Board of Health, 1885, pp. 64-65; also, *Hygiene and Public Health*, Parkes, second edition, pp. 207-215.

² Report of Special Committee on South Side Water Supply, Pittsburgh, December 23, 1887.

Among the many agencies affecting our water supplies are cemeteries, and we ought not to pass them unnoticed, for they are certainly in some localities a most dangerous source of pollution. It is now fully ascertained that the soil which contains decaying animal matter poisons, for great distances in the direction of the flowing currents, the ground-water of the stratum in which the matter decays. Under no circumstances should interments be permitted amid the dwellings of the living. In England, cemeteries cannot be located within six hundred feet of a dwelling-house; in France, not within three hundred and twenty-seven feet; and in Germany the prohibition extends to three hundred feet. Nor should the drainage from a cemetery be permitted to enter a stream of water that is used for domestic purposes. "The location of a cemetery should receive the most thoughtful consideration. The dead should be so buried that the living may not suffer. The nature of the soil and the topography of the adjacent country should be thoroughly examined in reference to drainage and water supply. A burial place should never be selected because it is a gift, or cheap. It should be sufficiently elevated above the surrounding region to receive free ventilation by the wind, which should have unobstructed access from all points."¹

From 1856 to 1866 there were twenty-one thousand deaths from cholera, and one hundred and fifty thousand deaths from typhoid fever, in England and Wales.² Until recently, in all of Great Britain, twenty thousand

¹ Report of Iowa State Board of Health, 1889, p. 108.

² Report of Brooklyn Commissioner of Health, March 10, 1884, p. 78.

persons died and two hundred thousand suffered annually from typhoid fever, and the majority of cases were probably produced by polluted water.¹ But now England has an efficient health administration which looks after the hygienic conditions of the people. The result is that typhoid fever has largely disappeared from among them, and for weeks and even months not a single case now occurs in the city of London. The people of the United States should also be protected by stringent hygienic regulations.

In Michigan the annual mortality from typhoid fever is about one thousand, while ten thousand people are annually afflicted with this disease.² In the United States thirty thousand people die annually from this fever alone. The mortality from typhoid fever in many of the eastern cities is proportional to the quantity of sewage which enters the water supplies.³ The annual death-rate from this disease per one hundred thousand inhabitants, in Brooklyn, is about fifteen; in New York city, twenty-five; and in Boston, forty; but in the city of Vienna, from 1851 to 1874, while impure well-water and a supply of water from the Danube were used, the annual death-rate was from one hundred to three hundred and forty per one hundred thousand inhabitants. By the use of spring-water in place of the former supplies, the mortality from typhoid fever in Vienna has been greatly reduced. During the last three years it has reached only eleven per one hundred thousand inhabitants.

¹ Report of Michigan State Board of Health, 1884, p. 116.

² Report of Michigan Sanitary Convention, Dec. 6 and 7, 1887, p. 24.

³ Report of Committee on the Pollution of Water Supplies, American Public Health Association, 1888, p. 5.

CHAPTER V.

MICRO-ORGANISMS.

PEOPLE who have never studied nature through a microscope have but little true conception of the real living world around us. The number of plants and animals with which we are familiar through the naked eye, is insignificant when compared with the countless myriads of living *Bacteria* which surround us, and can be seen through a powerful microscope.

The Dutch naturalist, Antonius van Loenwenhoeck, as early as 1675 observed and studied *Bacteria*, but our knowledge of these micro-organisms has been mostly attained during the last thirty years. In 1848, Fuchs¹ observed these minute bodies in animals dead from septic infection, and in 1849 and 1850 Brauell and Davaine observed them in the blood of sheep dead from anthrax; but no efforts seem to have been made to establish any genetic relation between *Bacteria* and disease until Pasteur's work on Fermentations appeared in 1861. Since that date, remarkable and interesting discoveries in Bacteriology have been made by Pasteur, Koch, Klebs, Cohn, Virchow, Burdon-Sanderson, Tyndall, and many others, from whom we have been given convincing proof of the validity of the "germ theory of disease."

¹ *On the Relations of Micro-Organisms to Disease*, Belfield, p. 4.

It is now almost universally admitted that *Bacteria*,¹ or *Microbes*, belong to the domain of botany, and are the simplest and minutest organisms in the vegetable kingdom. The great majority of these micro-organisms are harmless to the human system, and are beneficent agents in nature ; but some of them are *infectious*, the diseases that they produce being called *zymotic*, in consequence of their course resembling a process of fermentation. Such diseases as *cholera*, *typhoid fever*,² *diphtheria*, *scarlet fever*, and *erysipelas* belong to this class.

As long as the cause of these diseases was undetermined, the science of their medical treatment was groping in the dark ; and it is only since the genesis of many of our most dangerous diseases has been traced to micro-organisms, that the right treatment of them has become probable. The announcement that Dr. Robert Koch of Berlin has discovered a method of inoculation, by which all except the most advanced stages of tubercular consumption can be cured, has given an immense stimulus to scientific medical experiment, and it is hoped that his discoveries may be carried to all stages of this dreaded malady. Consumption and malaria are two of the most dreaded microbe diseases with which the human race is afflicted, and the discovery of the means of curing them and preventing their spread will undoubt-

¹ *Bacteria* = rods; *Microbes* = small living objects. These are commonly designated as *Germ*s.

² Every pathologist should read *Typhoid Fever ; its Preventable Causes*, by Dr. Robert Bartholow. This is republished in Report of Iowa State Board of Health, 1889. Every student in chemistry and biology should also read *Floating Matter of the Air in Relation to Putrefaction and Infection*, by Professor John Tyndall.

edly be the greatest benefit to humanity that medical science can give us. For it is said that owing to the exposure which soldiers are compelled to undergo, one-half of the deaths in the German army are caused by tuberculosis; and if medical statistics are true, malaria, in all its direct and indirect results, is held accountable for at least one-half of the mortality of the human race.

Since these are microbe diseases, it may be well to state briefly a few facts concerning the *Germ*s of disease. Many *Bacteria* are not more than one-fifteen-thousandth or one-twenty-thousandth of an inch in length, and it has been estimated that it would require four hundred million of them of average size to cover one square inch of surface.

Bacteria are present in many kinds of matter. They always inhabit the air we breathe and the food we eat, and even the purest natural water is never free from them. A cubic centimetre of average spring- or deep well-water generally contains from several hundred to several thousand of them; while a single wineglass full of polluted water is often found to contain more *Bacteria* than there are people on the face of the earth. *Bacteria* are indeed so abundant in nature and so difficult to separate from living tissue, that when our fingers, even after a thorough washing, have been brought in contact with the biologist's sterilized microscope slide, a dozen or more groups of them can be cultivated from it. And they are the most prolific organisms of which we have any knowledge, for in its multiplication a single *Bacterium* may become the causative parent of sixteen million five hundred thousand descendants in a day.¹

¹ *The Story of the Bacteria*, Prudden, p. 17.

Bacteria are classified according to their shape and structure. Thus the *Micrococci* are composed of single, spherical, or oblong cells; the *Streptococci* are composed of cells arranged in chains; the *Bacilli* are rod-like forms; while the *Spirilla* are of a corkscrew or spiral shape.¹

Although our most dreaded diseases are produced by *Bacteria*, the harmless forms of these micro-organisms have their beneficent uses in the economy of nature. Through their efforts sugar is converted into alcohol, and from the carbonic anhydride evolved, the cork of the champagne bottle is discharged with almost explosive violence. While one class is thus engaged in making alcohol, another class is fermenting it into acetic acid; and still other classes are servants to the baker in raising his bread.

It is to *Bacteria* that we owe the phenomena of fermentation and decay. They are the common scavengers of the earth. It has long been known that plants and animals bear a reciprocal relation, each producing the food that is required by the other. Plants take up simple compounds, like water, carbonic anhydride, and ammonia, and elaborate them into complex compounds suitable for the food of animals. Animals,² on the other hand, break down these complex substances and furnish them again in the simplest forms available for

¹ For an interesting elementary description of *Bacteria*, and methods for studying them, see *Micro-Organisms and Disease*, by E. Klein, M.D., F.R.S.

² The fundamental distinction between the chemistry of vegetable and that of animal life is that the former is eminently *constructive*, and the latter *destructive*.

plant food ; but still there is a large number of animal products that are not thus reduced, and not suitable for plants to assimilate. "These it is the function of the *Bacteria* to transform and prepare. They are the cooks of the vegetable creation. Every fermenting manure heap, every rotting vegetable and animal, is a great kitchen in which this preparation of vegetable food is going on. But for the constant beneficent work of the *Bacteria* the world would soon be choked up with the undecomposing remains of plants and animals ; and vegetable and animal life must alike perish. They are at once, then, the scavengers, caterers, and cooks of nature, and as no living beings are so widely distributed, so no living beings are more beneficent in their work." ¹

In an interesting investigation at the city of Paris,² it was found that in a cubic metre of air above ground there were ten thousand *Germ*s ; in the sewers, thirty-six thousand ; in old houses, forty thousand ; and in the hospital of Petie, seventy thousand. Dr. Percy F. Frankland has also shown that the number of *Bacteria* present in the air differs at different seasons of the year, the largest number being found during the summer months.

These micro-organisms are absorbed by water exposed to the air, and Dr. Frankland³ has found that the average river-water of England, like that of the Thames, contains about twenty thousand *Germ*s per cubic centi-

¹ *The Sanitary Era*, March, 1890, p. 106.

² *Water*, Moore, p. 7.

³ The Beneficent and Malignant Functions of Micro-Organisms, *The Sanitary Record*, Vol. LX. This is republished in Report of Maine State Board of Health, 1887.

metre. This number is greatly reduced when the water is submitted to storage and filtration, for the purified water from the Thames, used in London, contains only about four hundred *Germ*s per cubic centimetre; but there is, perhaps, no reliable artificial method for their entire removal, except by the agency of heat, and by slow filtration through compact substances.

The *Bacterium termo*, which is the agent of putrefactive decomposition, is found abundantly in polluted water. If a bottle of such water be left in a warm place for a few days, the water acquires a disagreeable odor, and, upon microscopical examination,¹ is found teeming with these micro-organisms and other low forms of life. Or, if a glass of the water is left uncovered for a few days, a thin coating will form on its surface, which, if placed under a microscope with a magnifying power of about five hundred diameters, will present an interesting field. In the words of Troussart,² "The whole field of the microscope is in motion; hundreds of *Bacteria*, resembling minute transparent worms, are swimming in every direction, with an undulatory motion like that of an eel or snake. Some are detached, others united in pairs, others in chains or chaplets or cylindrical rods." These *Bacteria* multiply and develop in endless succession, in accordance with the laws of their being, and

¹ A convenient method for preparing and examining a sample of polluted water for *Bacteria* is as follows: To a collecting-tube filled with the water add a few drops of a one per cent osmic acid solution to destroy its micro-organisms, and allow the water to remain quietly for a few hours for them to subside. Then collect the sediment, color it with a staining reagent, and examine it microscopically.

² *Hygienic Physiology*, Steele, p. 301.

they are significant of organic pollution. They purify water, however, by converting the organic into inorganic, and therefore harmless constituents. But a water which contains them in any great numbers should always be considered with suspicion.

In some instances, *Bacteria* are capable of being conveyed to great distances in water, without losing the vitality necessary to produce fermentation or disease. Indeed, it is a very difficult matter to deprive some *Bacteria* of their vitality; they may be frozen, or even heated to the boiling point of water, and yet many of them are not destroyed. They may be kept dried for years, and yet when in a favorable medium, *if pathogenic*, are capable of producing disease.

Wherever *Bacteria* are found abundantly, decomposing nitrogenous organic matter¹ is always present, and Pasteur has shown that they do not multiply without a putrefactive environment, but remain infertile until they perish. *Bacteria* of *putrefaction* and *infection* flourish most abundantly in a neutral or an alkaline menstruum, such as is generally found in decomposing sewage matter and the effluvium from sewers; but they are readily destroyed in acid solutions. It has also been observed that the *Bacteria* producing acid fermentations perish in alkaline liquids.

Standard authorities agree that alkaline waters are dangerous for drinking, since they may favor the development of *infectious Germs*. Water that contains an

¹ According to Lex, the three following substances are required for the existence of *Bacteria*: 1. an organic carbonaceous substance; 2. a nitrogenous substance, either inorganic or organic; and 3. a phosphate in small quantity.

excessive quantity of the alkaline carbonates tends to make the system alkaline, and physicians often find it necessary to put patients, suffering with digestive, intestinal, and renal diseases, upon distilled water as a beverage, and with happy effects.

The *infectious Bacteria* are liable to multiply rapidly on alkaline mucous membranes. This is the case with the *Micrococcus* of diphtheria, when carried into the air passages. The only guarantee against this disease is isolation from the micro-organisms that produce it. What is true of the air passages is also true of the alimentary canal, for in persons afflicted with digestive disorders, in which the gastric juice is constrained, *pathogenic Germs* may find a fertile soil and multiply with great rapidity. In the healthy human stomach infectious *Germs* do not thrive, as the reaction therein is acid; a free supply of gastric juice will kill and digest them.¹

A good corrective for alkaline polluted waters is sulphuric or phosphoric acid. These acids arrest putrefaction and destroy the *Germs*. Workmen, whose employment, location, and habits, favor an attack of a zymotic disease, sometimes prevent an epidemic by drinking water acidified with one or two drops of sulphuric acid per pint.² Sulphuric acid is also used with great advantage in treating cases of cholera and typhoid fever, by giving ten to thirty drops of the acid in water three times a day. Owing to the power of certain reagents in rendering *Bacteria* latent, or in destroying

¹ *The Sanitary Era*, October 1, 1888, p. 76.

² Report of Examination of Water from the River Schuylkill, Cresson, pp. 13-14.

them, there has arisen in modern medicine this antiseptic method of treatment. Hydronaphthol is also recommended as a corrective for polluted water; it is a powerful germicide, but it is harmless to the human system. Pyridine, a constituent of tobacco smoke, is also a powerful destroyer of *Bacteria*. It is claimed that men who use tobacco are less susceptible to zymotic infection than those who do not use it, and that women are more frequently attacked with typhoid fever and diphtheria than men. If this be true, it is, however, more likely due to the sex than to the antiseptic agent used.

The infectious *Bacteria* are thrown off with the excretions of persons suffering from zymotic diseases, and these *Germes* not infrequently find their way to water supplies, and therefore to persons who, from predisposing causes, may be in a suitable condition for their reception and multiplication, and for the production of a specific form of disease; but unless a suitable lodgement is found for the *Germes*, no disease will be produced by them. From the experiments of a distinguished investigator, it has been shown that the human body has enlisted in its service what may be called a microscopical militia, whose duty it is to ward off the assaults of the invading *Microbes*. These militiamen are the lymphatic cells, whose function in part is to swallow or annihilate the hostile *Bacteria* before they enter the blood. Where, of two persons exposed to the same contagion, one escapes and the other falls a victim, the explanation lies wholly in the fact that in the one case the sentries are victorious, while in the other they are defeated in their struggle with the invading *Bacteria*.

In the language of the "germ theory," certain con-

stituents of the system are exhausted by the infectious *Germ*s, and until they are restored, the body is protected from any further attack of the same disease. To exhaust the system of this nidus, a *Germ* less vigorous and dangerous than the disease-producer will sometimes suffice. If, then, after the feebler organism has exhausted the system without fatal result, the virulent *Germ* should find its way into the system, it will be harmless. *This is the whole secret of vaccination.*

A very interesting and valuable fact has been brought to light by the experiments of a distinguished European writer, who has shown that sometimes "two micro-organisms, either of which singly is harmful to the human body, may be deadly foes of each other. This was found to be true of the *Microbes* of diphtheria and erysipelas. Of a large number of persons afflicted with diphtheria, all those who were inoculated with erysipelas recovered, while those not so inoculated, died. It was noticed that those who recovered from diphtheria had only a very mild form of erysipelas, as if the *Microbe* peculiar to that disease had been exhausted in the conflict with his diphtherial enemy."

Each group of pathogenic *Bacteria* seems to have its specific organ for attack. Thus the *Bacillus tuberculosis* generally has its seat in the lungs; the typhoid *Bacillus* penetrates the mucous membranes of the intestines and accumulates in the spleen; and the *Micrococcus* of diphtheria produces extensive layers of false membranes in the fauces. We are, therefore, to assume that each zymotic disease is accompanied by its specific *Germ*; and that each *Germ* produces only its own kind. The doctrine that "like produces like" continues eternally

WASH. 1881

true, but there may be a gradual change produced by a change of environment. If we sow wheat only, we do not reap a crop of oats or barley; but just as wheat springs from wheat, so each zymotic disease has its accompanying distinctive *Germ*. And so, if we plant only cholera *Germ*s in our system, we do not reap a crop of small-pox or measles, but invariably a crop of cholera.

Bacteria have the power of elaborating organic poisons, known as *Ptomaines*, and the question as to whether zymotic diseases are the direct result of the action of pathogenic *Bacteria* upon certain organs, or the result of *Ptomaines* elaborated by them, cannot in the present state of knowledge be answered with certainty. In some cases, however, the disease seems to come from the organic poison. *Tyrotaxon* is the poison produced in the fermentation of milk by the agency of *Bacteria*, and it seems to be the cause of much sickness originating from spoiled milk. It produces a complexus of symptoms in the human system resembling those of cholera infantum, and Dr. V. C. Vaughan, who discovered this poison, suggests that this may be the chemical irritant producing this disease. And what is true of cholera infantum is perhaps true of typhoid fever, and many other diseases, but not at the same stage of life.

While some persons are easily infected, it is also true that many seem insusceptible to the *Germ*s of disease, and, although much exposed, they pass through long lives unscathed. "This insusceptibility varies indefinitely, or it may exist at one period of life and then unfortunately be lost, or a new and greater suscepti-

bility be acquired at other times. The conditions that determine susceptibility or insusceptibility cannot be defined in the present state of knowledge. There are certain periods of life when the human body cannot be infected,—infantile period, old age. At the extremes of life the typhoid *Germ*s can make no impression, because of the absence of necessary conditions. The essential lesions to constitute any one case of typhoid, are thickening, ulceration of glands situated in the lowest part of the small intestines (Peyer's patches), and similar changes in what are known as the 'solitary glands.' At the earliest period of life these glands are not sufficiently developed, and in old age they are too much wasted, to furnish a nidus for the reception and growth of the parasite. It is not possible to indicate the precise period when these glands acquire full development, or become too much wasted to take on the typhoid infection."¹

Bacteriology is the newest of the sciences, and yet it has become one of the most interesting fields for the truly scientific investigator. No chemist and no pathologist can afford to remain ignorant of what has already been learned of the workings of the microscopic world around us; for many of the most interesting chemical changes are produced by *Bacteria*, and many of the most dangerous maladies have been traced to them. A description of the *Bacteriological* methods of investigation, with the remarkable results achieved, would be of interest, but the elementary character of this treatise forbids it here.

¹ Report of Iowa State Board of Health, 1889, pp. 43-44.

CHAPTER VI.

WATER SUPPLIES.

Rain-water. — There is a popular idea that rain-water, as it falls, is perfectly free from impurities ; but, in fact, the first fall of rain after a drouth is swarming with living organisms, which multiply and perish, polluting the water with themselves and the products of their decomposition ; but fortunately the living organisms are generally harmless. Even the purest unfiltered air¹ contains myriads of these motes which can be seen in the sun-beam with the naked eye, but they are washed from it by the descending rain. Two hundred thousand micro-organisms are often found in a litre of water that falls at the beginning of a storm, the number being usually greater in summer than in winter. The principal genus of *Bacteria* found in rain-water is the *Micrococcus*, but other genera are also found, nearly all of which are in the stage of *spores* instead of *adults*. Besides *Bacteria*, spores of *Fungi* and other microscopic plants, together with the pollen of flowers and grasses, are found in rain-water.

The exhalations that rise from decomposing organic matter, and float in the atmosphere, are also carried

¹ *Practical Hygiene*, Parkes, seventh edition, pp. 132-151.

down by the rain, so that the first rain that falls during a storm is always more or less impure, and unfit for drinking ; but the air becomes purified in a short time, and the rain that falls thereafter is approximately pure water. The British Rivers Pollution Commissioners concluded that "half a pint of rain-water often condenses out of about three thousand three hundred and seventy-three cubic feet of air, and thus in drinking a tumbler of such water, impurities which would only gain access to the lungs in about eight days, are swallowed at once."¹ These impurities consist of ammoniacal salts, nitrous and nitric acids, sodium chloride, calcium compounds, and organic matter ; and when the water has drained from the roofs of buildings, after a dry season, additional impurities are dust, dead insects, excreta of birds, and probably dried disease germs. The total solids from rain-water usually amount to two or three grains per gallon. As the rain falls, it becomes thoroughly aerated ; but rain-water has usually a flat, smoky taste, owing to the small amount of carbonic anhydride and alkaline salts in it.

In Iowa the average annual rainfall is thirty-one inches.² Consequently, on one hundred square feet of surface, about nineteen hundred and thirty-two gallons of rain-water will fall annually. The average evaporation from the roofs of buildings is about twenty per cent of the rain that falls upon them, so that the eighty per cent of water that may flow into cisterns from each one hundred square feet of surface is about fifteen

¹ *Potable Water*, Ekin, p. 9.

² *Treatise on Meteorology*, Loomis, p. 117.

hundred and forty-six gallons per year, or four and two-tenths gallons per day, on an average.

In the rural districts of our northern latitude, where the ground-water is generally quite pure, rain-water is not usually collected for general domestic purposes. When the ordinary source of water is excessively hard or impure, rain-water is, however, sometimes used for drinking ; but it is usually collected for bathing and laundry use only, on account of its softness.

But in some of the southern cities, near the Gulf of Mexico, where it is impossible to secure a supply of pure well- or spring-water, rain-water is used extensively for all domestic purposes, and many of these cities derive their entire domestic water supply from rain. "In Galveston, Texas, where the island is so low that the use of well-water is entirely out of the question, each dwelling-house is furnished with one, two, or more large cisterns constructed of cypress wood, whose capacity varies from one thousand to forty thousand gallons ; the cistern is generally elevated about two to three feet from the ground, is covered with a lid which is lifted a short distance from the top, and which allows proper ventilation. In some cases the cistern is placed in an independent enclosure made for the purpose, in others they are placed in the wood-shed, but far the greater majority are placed in a balcony or on the shady ground near the low oleander trees, and have but little protection, if any, from the sun. Some are made of cement and sunk underground, within a very few feet of the cesspool, which is naturally very shallow, as it is impossible to dig more than two or at the most three feet in the sand and avoid water. These underground cisterns are oft-

times saturated with the emanations from the unclean cesspools in close proximity.”¹

It is very important in the construction of cisterns for storage of drinking-water that great care should be exercised in preparing the walls against any leakage from cesspools and privies. The water should have a supply of fresh air, but should not be exposed to sunlight, or even diffused light. Rain-water collected near the end of storms, and thoroughly filtered through sand and charcoal, is wholesome, and can be kept suitable for drinking by storage in properly constructed cisterns.

Well-water. — The purity of well-water depends mainly upon the depth and situation of the well, and the nature of the surrounding soil. The water in *deep wells* is separated from the surface by an impervious stratum. The water in artesian wells is nearly free from organic impurities, but it is usually highly mineralized, and the temperature is oftentimes objectionably high. Deep wells, when properly made, are also nearly free from organic impurities, but their waters are impregnated with hardening salts. Such waters are not best suited to the digestive powers of man; and every intelligent groom and herdsman knows that such waters are also more prejudicial to horses and cattle than even the water of a muddy stream. Although the water from deep wells and springs is generally sparkling and pure at first, it soon gives rise to a growth of *Algæ*, if exposed to sunlight and heat in ponds or open reservoirs; but if stored in covered reservoirs, where sunlight cannot enter, it remains pure for a long time. A growth of

¹ Report of Connecticut State Board of Health, 1885, pp. 254-255.

Algæ is also often seen in the orifices of pipes discharging artesian and other deep well-water.

Surface wells depend for their main supply of water upon the area immediately surrounding them, no matter what their depth, and these are the wells most frequently used. The abundance of filth in densely populated cities renders the soil unfit for the filtration and storage of water ; and surface wells in such soil furnish only a polluted and dangerous supply, as the water is not sufficiently aerated for the oxidation of its organic matter. *These wells are frequently situated in too close proximity to dwellings, stables, cesspools, privy-vaults, and other sources of pollution, and they are therefore sometimes important factors in disseminating disease.*

Rain-water, as it passes into the earth, extracts from the soil quantities of impurities, like the products of decaying vegetation and the filth and excrement of animals, which it carries down into the circulating currents, and it occasionally happens that the drainage of cesspools and privies finds a direct channel into the well. *The germs from diseased persons thus find their way to the water supply, and some surface wells are nothing more than receptacles for diluted excrementitious matter.*

“The common practice in villages, and even in many small towns, is to dispose of the sewage and to provide for the water supply of each cottage, or pair of cottages, upon the premises. In the little yard, or garden, attached to each tenement, or pair of tenements, two holes are dug in the porous soil ; into one of them, usually the shallower of the two, all the filthy liquids of the house are discharged ; from the other, which is sunk below the water-line of the porous stratum, the water

for drinking, and other domestic purposes, is pumped. These two holes are not unfrequently within twelve feet of each other, and sometimes even closer. The contents of the filth hole, or cesspool, gradually soak away through the surrounding soil and mingle with the water below. As the contents of the water hole, or well, are pumped out, they are immediately replenished from the surrounding disgusting mixture, and it is not, therefore, very surprising to be assured that such a well does not become dry even in summer. Unfortunately, excrementitious liquids, especially after they have soaked through a few feet of porous soil, do not impair the palatability of water; and this polluted liquid is consumed from year to year without a suspicion of its character, until an outbreak of epidemic disease compels attention to the polluted water. Indeed, our acquaintance with a very large proportion of this class of potable waters has been made in consequence of the occurrence of several outbreaks of typhoid fever amongst the persons using them.”¹

“The well-waters of New Orleans are unfit for use. They are but little less impure than the sewage water carried off by the drainage canals, yet they are reported as being employed for family use, in bakeries, and for stock, especially in summer, when the cistern supply fails. The site of the city is waterlogged to within a few feet of the surface. One well, on Chestnut Street, the least impure of those examined, is only ten feet deep, and contains seven feet of water. The saturated soil is of great depth, and the ground-water is practi-

¹ *Domestic Water Supply of Great Britain*, Sixth Report of Royal Commissioners, pp. 68-69.

cally stagnant. The filtration into the wells is insufficient even to free the water from turbidity. Organic matter is unaffected by the process."¹

The drainage section of a surface well may be likened to the contents of an inverted cone, the base of which is the surface of the drained ground, and the apex the bottom of the well. In a porous soil the drainage area is sometimes quite large and the water impure. It is said that the circulation of water is sometimes so thorough in the earth that if a barrel of kerosene oil be placed ten feet under ground, every well within a quarter of a mile will be contaminated, and the oil will be apparent to the taste.² It has been demonstrated that in compact soils, the level of the ground-water is influenced by pumping, for a distance of two hundred feet in all directions around a well, while in loose, gravelly soils, the circle of influence may have a radius of more than two thousand feet.³ This produces a circulation of water toward the centre, and consequently a washing of the filth of the soil into the well. *No stable, cesspool, privy-vault, or other source of contamination, should be within this radius.*

Many severe outbreaks of epidemic diseases have been traced to the use of surface well-water in cities, and there is strong reason to believe that sporadic attacks of typhoid fever often occur in isolated country homes from the same cause. When scientific views concerning the pollution of well-waters are disseminated, surface wells will be rapidly abandoned by the intelli-

¹ Bulletin of National Board of Health, April 17, 1880.

² *Water*, Moore, p. 31.

³ *Water Supply*, Nichols, p. 110; also, *Hygiene and Public Health*, Parkes, second edition, pp. 27-28.

gent classes. It is often difficult to persuade the owner of a polluted well to abandon it, since the water may have an agreeable taste, and may have been used for years with impunity. The ignorant cannot often be convinced by the results of scientific investigation; they require the "test of experience," and to some there is no test convincing of the pollution of water, except the actual production of sickness and death.

Drinking-water should be well aërated. The well should be exposed to fresh, circulating air, if possible, and situated where there is no flow of water into it from contaminating sources. Well-water sometimes becomes impure from the absorption of floating matter from a stagnant atmosphere. Wells should never be situated in cellars, on account of the stagnant, impure air which is generally in them. Wells situated near a house, from necessity, are generally closed, but in all cases there should be some means of ventilation. Even some methods of agitating the water have been advocated by sanitarians. The "old oaken bucket," chain pumps, and similar agencies for lifting, may assist purification and aëration, by agitating the water.

In the ordinary method of bricking or walling a well, no protection is offered against surface drainage, and a deep well thus constructed is no better than a surface well. Open wells should always be walled with hydraulic cement above the water-line, to prevent the admission of filth. Surface contamination is also prevented by the use of deep "driven wells";¹ with these the only

¹ These are also known as "Tube," "American," "Abyssinian," and "Norton" wells.

pollution comes from the downward circulating currents. Wooden curbing for wells is a serious source of danger, as the wood soon becomes rotten, contaminates the water, and promotes the growth of *Fungi*. It also affords lodging for myriads of insects which fall into the water and die.

Spring-water. — Springs¹ are fountains of water which flow from subterranean channels. This term is sometimes incorrectly applied to mere shallow pits, filled with water oozing from marshy surroundings, and with little or no visible outflow. Water which finds its way into a porous rock, between impervious strata, generally issues in springs along the outcroppings of the pervious stratum. The direction of dip generally determines the direction of the ground current, the water seeking its lowest level; and a sudden change in dip often gives rise to springs, or the water may flow from the lowest outcroppings of the pervious stratum. Springs are, therefore, similar in purity to deep wells, for these wells derive their supply from the subterranean channels. The water which gathers into these channels descends from the earth's surface; and if the surface water is polluted, the springs which receive their supplies from it are liable to be impure. The organic constituents, in filtering through the earth, may, however, oxidize to harmless inorganic products if the filtering bed is sufficiently deep; but disease germs are not thus destroyed.

Average porous soil contains about two hundred and fifty times as much carbonic anhydride as does the air,

¹ For a consideration of the origin of springs, see Winchell's *Geological Studies*, third edition, pp. 7-12.

under ordinary conditions, and this is taken into the percolating water as it filters into the subterranean channels, rendering it especially palatable. It is this carbonic anhydride in water which dissolves limestone, converting it into a soluble bicarbonate.

Spring-water which flows from hill or mountain sides is generally cold, and has a uniform temperature the year around. Springs may furnish the best water for drinking, as they are often nearly free from organic impurities, and their waters are very palatable, from the gases and salts held in solution, but they are generally unsuitable for technical purposes, on account of hardness. They are superior to wells having water of the same nature, on account of their freedom from the accumulated matter which is always found on the surface of well-waters. A perfectly pure spring-water is certainly our healthiest natural beverage. Such waters are abundant, and can often be easily obtained. Country residences should be located near perennial springs, if possible, and their waters adopted generally or universally for drinking. Spring-water is so much superior to surface well-water for domestic purposes that some cities have incurred considerable expense to introduce it. The city of Vienna uses water brought from springs sixty miles distant, and has freed itself of much sickness, such as prevailed there when filthy river and surface well-water only was used.

River-water.—Owing to available water power, means of transportation by boats, and easy drainage, streams are the natural localities on whose banks manufactories and cities are generally located. From these enterprises pollution is added to the water courses. Nearly all

improvements in the soil also tend to contaminate the streams, for "the surface waters which formerly ran from the mountains and forest lands, now run off from cultivated and enriched fields, or from the roads and streets of towns and villages."¹ Rivers are the natural drains of the territory through which they flow, being fed by rains, small streams, springs, and surface drainage. "They are the receptacles of all the waste products of the inhabitants of the district; they receive the contents of sewers, cesspools, and privies; the offal of distilleries, slaughter-houses, and tanneries, and the refuse of factories. Into them are thrown carcasses of dead animals, as the most expeditious method of burial. From swamps they receive the matter of vegetable decomposition, and are discolored by flowing over beds of peat."² The factories that are especially objectionable are sugar refineries, and starch, glucose, and dye works. Rivers are also sometimes polluted by the filth from stock-yards. Many of the organic substances which are washed into rivers from cities situated on their banks undergo decomposition, giving rise to products, some of which have the power to produce disturbances in the human system, and others to propagate the germs of disease.

The Prussian government protects its public water supplies by forbidding the discharge of sewage into its rivers. Some of our states also have laws protecting the water courses, making it a criminal offence to throw any polluting substance into water which shall after-

¹ Report of New Jersey State Board of Health, 1884, p. 90.

² *Water Supply*, Dickinson, p. 5.

ward be used for drinking. Some of our state and local boards of health are empowered to prohibit any nuisance which may tend to produce disease, but as a nation our sanitary laws are unsatisfactory. The pollution of streams can only be prevented by stringent regulations, and so at present it is absolutely impossible to prevent the pollution of many water courses.

One of the sanitary problems now needing solution, is how to get rid of sewage and protect our rivers. It has been suggested that the larger streams which furnish water for city supplies should be kept pure, while the smaller ones might be used for carrying off sewage, when they are not used for domestic supplies. "It is evident that nothing is more unphilosophical than that one town should be allowed to discharge its sewage into a water course that is the most available source of water supply for a town lower down on the stream. Each river-basin should be under the control of some central authority by which conflicting interests should be harmonized. An accurate survey should be made of the whole area, and no town should be allowed to introduce a water supply without due consideration being given to the future of the supply, and to the question of disposing of the sewage of the town supplied. Moreover, while sanitary conditions are of the highest importance, manufacturing interests must also be considered, and no undue burden laid upon legitimate industries."¹

River-water, below the discharge of city sewage, is a filthy and dangerous beverage, and notwithstanding its natural purification by sunlight, by oxidation, and by

¹ *Water Supply*, Nichols, pp. 77-78.

living organisms, it may never be free from disease germs. A stream which has received much filth in its course is unfit for domestic use, unless the volume-ratio of the filth to the water is inappreciably small. The amount of impurities of streams in rural districts, from the decay of vegetation, is always greatest in the fall, and that from suspended matter is always greatest in the spring.

River-water originating in mountainous districts is unquestionably the best for city supplies, as under ordinary conditions it is softer than well- or spring-water, and is freer from organic and living matter than surface wells and stagnant ponds and lakes. The objections offered against the use of river-water are on account of its high temperature, frequent turbidity, and its liability to contamination; and it is true that some rivers furnish water only fit for hydrant and manufacturing purposes. But by the use of ice, efficient systems of purification, and proper precautions against pollution, river-waters are generally excellent supplies for cities and towns, where an abundance of pure water is needed. In the ground-water system for central filtration, the wells receive only a part of their water from rivers on the banks of which they are situated, as the ground-water is constantly flowing toward the river-channel.

Lake- and Pond-Water. — Lakes are the reservoirs into which rivers and other streams empty, and when small their waters are not widely different from their sources. They are not often entirely free from suspended matter, but their waters can be easily rendered pure by natural settling basins. Lakes are less likely to be rendered turbid than

streams. The water is somewhat purified by the sedimentation of its suspended matter, and it remains cold during the summer. The water of the Great Lakes is, however, rendered impure near the shores by the discharge of sewage from the cities situated near them. And cities, like Chicago, which use a lake-water supply, are compelled to extend their receiving mains into the lake, beyond the limit of impurification.

Pond-water often becomes unfit for domestic use, from the growth of *Algæ* and fresh-water *Sponges*.

Water for Public Schools. — The water supply for public schools, asylums, hotels, and all other places where people are gathered together, should be exceedingly pure. One of the most potent factors in originating and spreading diphtheria, and scarlet and typhoid fever in schools, is the water used by the children, from surface wells and stagnant streams. The mere presence of these infectious diseases is all that is needed to inaugurate a general epidemic. There is scarcely a well supplying a public school in Iowa that is not suspicious. If not actually polluted, many of the wells are surrounded with dangerous agencies, such as privies, stables, and filthy streets and alleys. Dr. Chancellor,¹ secretary of the Maryland State Board of Health, says there is not a well-water in the whole state of Maryland fit for domestic use.

City schools should in all cases be supplied with water from water-works, when there are works in operation, and analyses show that their water is pure and safely potable. "Village and country schools should have

¹ *The Baltimore American*, July 31, 1889.

the well at least one hundred feet from any privy or stable, and the topography of the contiguous surface should be such as to secure rapid and free drainage in every direction from the well for the farthest possible distance. It should be free from the shade of trees and accessible to uninterrupted air-currents." ¹

¹ Report of Iowa State Board of Health, 1889, p. 82.

CHAPTER VII.

NATURAL PURIFICATION.

STREAMS are partially purified by the sedimentation of their suspended matter,¹ which takes place as the velocity of the current diminishes. A stream which is very turbid after a heavy rain may soon become clear, owing to its diminishing velocity, when the insoluble matter either sinks to the bottom or is precipitated along the banks. The retarding influence of tidal waves near the mouth of streams that empty into the sea also assists in the precipitation of suspended matter; and Barus² has shown that the sedimentation of fine particles is also promoted by the action of salt water, and that there is a rapid precipitation of silt where rivers enter the sea. This is quite likely one of the principal forces that produce and retain the "*Bar*" in the Mississippi River at its mouth. As the mineral matter subsides, it generally carries down with it much of the flocculent organic matter that would otherwise remain in suspension for many days.

¹ "The water of the Mississippi contains forty grains of mud per gallon; and it is estimated that this river carries four hundred million tons of sediment per annum into the Gulf of Mexico. The Ganges is said to carry down six billion three hundred and sixty-eight million cubic feet annually." — *Report of American Public Health Association*, Vol. I., p. 536.

² Bulletin, No. 36, United States Geological Survey.

An apparent purification of polluted water is effected by dilution, and the self-purification of many streams is largely due to this cause. The waste products of chemical factories, when poured into rivers in large quantities, are sufficient to render the water wholly unfit for domestic use, but in the course of a few miles from the factories the pollution becomes so much diluted that the water is rendered harmless. Some of these chemicals act as antiseptics and prevent the multiplication and growth of vegetable and animal life. In some cases, however, these chemicals or their products furnish a rank growth of *Algæ*, and the water is thereby rendered so objectionable that even fish cannot survive in it. This is the case with the Iowa River pollution.¹

The mineral impurities of streams are sometimes removed in mingling their waters with other streams of a different nature, or by flowing over rocks which act chemically upon them. This is beautifully illustrated in the purification of the Schuylkill River before it reaches Philadelphia.² This river receives the drainage from many mines, and is in its upper course highly charged with iron salts and free mineral acids, and its water is unfit for domestic and manufacturing purposes. In its course, the river passes through an extensive limestone district, and into it are emptied several large streams, highly charged with calcium bicarbonate. The free acids are thus completely neutralized, and the iron and much of the calcium are precipitated. At Phila-

¹ Bulletin of Iowa State Board of Health, July, 1889.

² *Examination of Water for Sanitary and Technical Purposes*, Leffmann and Beam, pp. 10-11.

delphia the water is soft, and is superior to the water at the source of the river or at the middle Schuylkill region, as it contains only traces of iron and a small amount of calcium sulphate.

Running water, especially when it flows over cataracts or is thoroughly agitated in the air, absorbs oxygen to such an extent that its organic matter becomes rapidly oxidized. The purification of water is also greatly promoted by sunlight and warmth, which are nature's most efficient agencies of purification. "The pure water of mountain streams and swiftly running brooks and rivers owes its freedom from organic impurities largely to its continued and violent contact and admixture with atmospheric air."¹ Some organic substances easily oxidize into ammonia, nitrites, nitrates, and carbonic anhydride, while others, like muscular fibre, may remain for months in water, and still be recognizable under the microscope. These chemical changes take place most rapidly in summer, owing to the favorable conditions of heat, light, and motion; but in winter the oxidation is retarded by the low temperature and the ice formations which shut out the light and air and impede the motion of the water.

The pollution of English streams is carried to such an enormous extent that the waters of many, where city sewage enters them, are actually offensive, and during the summer months, owing to the stench, the passenger traffic is forced to the railroads. In some of these streams the whole surface of the water, for some distance below sewage entrance, is in a state of commotion,

¹ *Water Supply of U. S. Capitol*, 49th Congress, 1st Session, Ex. Doc., No. 154, p. 20.

owing to the evolution of gas bubbles, and the water is so foul that it cannot be used in the boilers of the little steamers that ply across the rivers. Immediately below the entrance of sewage no life can exist in the water, on account of the presence of ferrous sulphate, which is a disinfectant. In their course, however, the water and banks become blackened from the formation of sulphide of iron, and with this formation the sewage fungus (*Beggiatoa alba*) appears. Further on in their course, the black color of the water and the fungus decrease and disappear, and in their place vegetation is luxuriant, fish abound, and the water becomes clear and apparently pure, from its dilution and oxidation, and from the agency of vegetable and animal life.

The distance which running water requires for its *apparent purification* depends mainly upon the extent and nature of its pollution, the dilution by inflowing streams, and the agitation of the water in its course. It is safe to say that it generally requires from five to twenty miles.¹ Professor C. F. Chandler has shown, by chemical investigation, that the Hudson River water is purified of its decomposing organic matter in the six-mile flow from Troy to Albany.

But self-purification is no guarantee that running water is perfectly wholesome at any distance below a point where it is certainly polluted with the contents of sewers and privy-vaults, or the products of decomposition of vegetable and animal matter. The question as

¹ Report of Massachusetts State Board of Health, Vol. VII., p. 146; also, *Water Supply*, Nichols, p. 71. The Royal Commissioners concluded, however, that running water is so slowly purified that there is not a river in England sufficiently long to dispose of a moderate amount of sewage, through natural agencies.

to what extent must impure water be diluted or oxidized to render it safe for domestic purposes cannot be answered. Mere dilution of polluted water does not render inoperative the action of living *Bacteria*, owing to the marvellous rapidity of their reproduction; and, under favorable conditions, it requires only a few days for pathogenic *Bacteria* to render water exceedingly dangerous, although in other respects it is comparatively pure. "Admitting the presence of disease germs in a liquid, the liquid may be diluted until the chance of taking even a single germ into the system is so small that it may be disregarded; and yet, if the prevailing theory be true, a single germ, if taken, might produce disastrous results. It is easy to push the demands for purity to an absurd extent; all reasonable precautions should be taken to insure purity, but there is a point beyond which it is foolish to attempt to go. In the present state of our knowledge we should, however, err on the side of safety, and the mere fact that chemical analysis fails to detect impurity should not be accepted as a guarantee that a water is fit to drink."¹

In freezing, water is partially purified,² as this operation eliminates a large portion of its suspended matter, but the inorganic salts, and the organic constituents, are only partially removed. The experiments of Dr. C. P. Pengra³ show that water, in freezing, is only freed

¹ *Water Supply*, Nichols, p. 71.

² *On Bacteria in Ice and their Relations to Disease*, Prudden; *Our Ice Supply and its Dangers*, Prudden; *The Dangers of Impure Ice*, The Sanitarian, May, 1882; also, *Impure Ice*, Report of Connecticut State Board of Health, 1883.

³ Reports of Michigan State Board of Health, 1882, pp. 48-50, and 1884, pp. 79-81.

of about fifty per cent of its organic crystalloids, twenty per cent of its colloids, forty per cent of its mineral salts, and ninety per cent of its *Bacteria*. It is, therefore, evident that ice may be a prolific source of disease, and many dangerous epidemics¹ have been caused by it. The impurities, excluded by freezing, remain in the unfrozen water in a concentrated and more dangerous form, and this may in part explain why typhoid fever often prevails, and is of such a severe type, during cold, winter weather.

In some of the southern cities artificial ice has forced the natural product from the markets on account of its cheapness. In some localities distilled water only is used for the ice manufacture, in which case the purest product is made. When well- or stream-water is used in the machine, care should be exercised to secure the purest water possible, since in most of the machines the entire water is frozen, and there is no chance for escape of impurities. Ice machines are also used in hotels and cafés for freezing ices and creams, but in such machines pure materials only are supposed to be used.

The soil may act as a mechanical purifier of water, by the removal of suspended matter as the water filters through it, and as a chemical purifier, by its oxidizing and other chemical action upon the organic impurities, whether they are held in suspension or solution. The filtering power of soil is found to vary greatly.² Sand

¹ Report of Massachusetts State Board of Health, Vol. VII., p. 465; also, Report of Connecticut State Board of Health, Vol. II., p. 90.

² Report of Michigan State Board of Health, 1876, pp. 110-111.

and gravel act mainly as mechanical filters, while ferric oxide is the oxygen-carrier of the soil. In general, a coarse soil is not so efficient in its mechanical and chemical action as a similar finer one; and every soil which has been charged with organic impurities is unquestionably inefficient. Even a good filtering soil which receives an excess of impurities becomes, at last, ineffective. "The surface impurities which accumulate with increasing population are carried farther and farther downward till finally the earth and sand will intercept no more of them; and the water passes in its impure, though possibly clear and sparkling state, to the wells, to become the cause of sickness with all its attendant evils."¹

Too much confidence is often ignorantly placed in the purifying power of the soil. From experiments instituted by the National Board of Health,² it appears that sand and gravel interpose absolutely no barrier between wells and the *Bacteria* of cesspools, privy-vaults, and cemeteries, lying even at great distances from them. In further support of this view, one celebrated case will suffice. In August, 1872, an outbreak of typhoid fever occurred at Lausen, near Basel, in Switzerland.³ The village water supply was from a spring at the foot of the Stockhalden. Suspicion was attached to this water; for it was found that the six houses using well-water were free from the disease, but scarcely one of those using the spring-water escaped. Upon investigation it

¹ Report of New Jersey State Board of Health, 1884, p. 90.

² Report of National Board of Health, 1882, p. 582.

³ *Nature*, Vol. XIII., p. 447.

was found that typhoid fever had occurred at a farmhouse on the opposite side of the Stockhalden, and that the drainage from this house went into a brook, a part of which passed into the mountain, about a mile distant from Lausen. Large quantities of salt were thrown into the stream, and the salt was soon detected in the Lausen supply, thus proving the connection between the two. Several hundred pounds of flour were then thrown into the stream, but not a trace of it was detected in the water supply, showing the thorough filtration of the water in passing through the mountain. The case was elaborately investigated by Dr. A. Hagler of Basel, and is of the greatest interest in showing that the most thorough filtration through soil is insufficient to remove typhoid fever germs from polluted water.

Finally, we are indebted to low forms of life for much of the natural purification of water. The decomposition of organic matter is the joint work of a number of independent organisms, the results of one class following those of another until organization is entirely destroyed.

The *Entomostraca* and other low forms of animal life, owing to their fecundity, are very important factors in removing organic impurities from water. Some of them seem to act mostly as catalytic agents, producing chemical changes by which the noxious organic constituents are converted into harmless products.

Notwithstanding what has been said concerning decomposing *Algæ*, the living forms of *Algæ* should not be considered an unmitigated evil, as most of them are really purifying agents, since they assimilate the dissolved organic matter in water. They also assimilate the carbonic anhydride, ammonia, and nitrogen acids

produced by lower forms of cryptogamic life. The main function of *Fungi* in the purification of water is apparently the oxidation of organic carbon and nitrogen.¹ Next of importance is the great army of *Bacteria*, which embraces many families of similar physiological structure; but the families are endowed with very different chemical powers. They sweeten water by a chemical process necessary for their own nutrition; and our water supplies would become magazines of deadly poisons, were it not for the myriads of these micro-organisms which attack dead organic matter, and cause its elements to enter into new and useful combinations. One class of *Bacteria* converts the nitrogen of nitrogenous organic matter into ammonia; another class elaborates this ammonia into nitrous and nitric acids; while another class is engaged in converting organic carbon into carbonic anhydride. Experiments² show that sterilization of polluted water largely arrests the decomposition of its organic matter, for ozone and hydrogen peroxide are then required to oxidize it under ordinary conditions; but when such water is subjected to biological agencies, it is purified as usual. Indeed, it appears that the removal of organic impurities is more of a biological than of a chemical process; and *in considering the natural purification of water, the action of micro-organisms should have the first rank, although some of them are pathogenic.*

It is well known that these chemical changes are more

¹ Report on the Waters of the Hudson River, Chandler, January, 1885, pp. 7-14.

² Report of Kansas State Board of Health, 1887, pp. 328-329.

rapidly effected when the water filters through the pores of the soil, than when it is stagnant, or even when it is flowing in the current of a stream. This is explained by the fact that the purifying *Bacteria* mainly have their abode in the three or four feet¹ of surface soil of the earth, and that they so modify the organic matter of water; as it passes through this layer of soil, that the roots of living plants can absorb and assimilate it. But while these *Bacteria* purify the downward-flowing waters, through their upward movement, they tend to accumulate in the surface water, and to spread themselves on the surface of the soil. Pasteur asserts that the excrementitious cylinders, left by earthworms in their upward migrations, are infested with germs, brought up to the surface, and that when they disintegrate by rains, the germs are spread over the fields, and animals become infested by eating the grass.²

¹ Report of Committee on the Pollution of Water Supplies, American Public Health Association, 1888, p. 11.

² *The Sanitary Era*, March, 1890, p. 107.

CHAPTER VIII.

ARTIFICIAL PURIFICATION.

Processes. — Water may be artificially purified by the following processes : 1. boiling ; 2. distillation ; 3. aëration ; 4. sedimentation ; 5. precipitation ; and 6. filtration.

Boiling. — By boiling polluted water the living organisms in it may be entirely destroyed. *Fungi* and *Algæ* are easily killed in this way ; but to destroy *some Bacteria*, heat must be applied for several hours to the water containing them. Professor Tyndall¹ has shown that there are periods in the life of *Bacteria* when they can resist the action of boiling water ; but, as they soften before propagation, water containing them can be completely sterilized by repeated boiling, for at the proper time, this not only destroys the *Bacteria*, but it destroys their *spores* as well. In order, then, to guard ourselves against these organisms, polluted water should never be used for drinking, without first being boiled for some time (two or three hours), as this prolonged operation thoroughly sterilizes it. Indeed, it is, perhaps, true that the two most effective measures which can be taken in avoiding zymotic diseases, consist in boiling all the water and the milk we use for drinking.

¹ *Floating Matter of the Air in relation to Putrefaction and Infection*, Tyndall, pp. 210-216.

Distillation. — Water may be freed from its solid impurities by a process of distillation.¹ In this way, inland bodies of water and the seas become saline from the concentration of their mineral constituents, while water in its crystalline purity evaporates from the surface. In the first part of distillation, the absorbed gases are liberated, and pass over and out with the distillate. It has also been claimed that *Bacteria* and their *spores* are carried over with the distillate, but the evidence is very unreliable. The flatness of distilled water, which is always objectionable at first, is said to be preferred by some people who have accustomed themselves to it; but this objection can be partially overcome by aëration. Distilled water is not generally used for drinking except by persons afflicted with renal and bladder difficulties. But it is said to be used regularly on the coast of Chili,² where it is made from sea-water, and is used oftentimes on long ocean voyages and expeditions, where fresh water cannot be obtained. As coal will ordinarily distil from ten to fifteen times its weight of water, there is an advantage in conveying coal instead of fresh water on board of ships.

Aeration. — Artificial aëration is a process by which we imitate nature in the purification of water. This oxidizes organic matter to harmless products, and renders the water highly palatable. As a process, aëration was first introduced by Lind more than a century ago, for the purification of water on the western coast of Africa. This process has since been used on a large

¹ *Water Supply*, Nichols, pp. 189–193.

² *Water Analysis*, Wanklyn and Chapman, sixth edition, p. 107.

scale in Russia, by allowing the water to flow down a series of steps, passing through wire gauze as it descends, and it has also been used on a small scale in Paris. But artificial aëration has only recently been introduced in this country for the purification of city water supplies. Professor A. R. Leeds,¹ in March, 1883, originally proposed aëration to the special commission of engineering experts, appointed to take steps for the improvement of the Philadelphia water supply. At that time the Schuylkill water was temporarily offensive, owing to insufficient aëration, and Professor Leeds proposed to remove the objection by pumping air, under great pressure, into this water supply. But the experts were not favorable to aëration as an engineering device, and were too conservative to adopt Professor Leeds' recommendation at that time; and it was not till aëration was successfully used for the Hoboken water supply that the Philadelphia Council appropriated ten thousand dollars for the purchase of air compressors, and the introduction of this process.

A few years ago the water supply of Hoboken, New Jersey, became extraordinarily offensive in odor and taste, and an examination of it, by Dr. Leeds, showed that this water was also deficient in oxygen. The water for this supply was first artificially aërated in September, 1884. This was at New Milford, where the water is pumped from the Hackensack River through a main seventeen miles long, one hundred and fifty-six feet

¹ I am indebted to Professor Leeds for communicating to me, February 16, 1890, many interesting facts pertaining to the Philadelphia and Hoboken water supplies.

above the level of the pumping-station. The reservoir has a capacity of fifteen million gallons, and the daily consumption is about five million gallons. Again, in 1887, the water, during the excessive heat of mid-summer, was found to lose its oxygen while impounded in the reservoir, although it entered it charged with oxygen to saturation, and patches of green *Algæ* appeared on the surface of the water in the part of the reservoir most remote from the entering main. A second air compressor was then introduced, and a pipe led around the sides of the reservoir at the bottom, to which twelve branches were attached, with distributing noses. On admitting the air through this arrangement the water at the corresponding points was kept in violent agitation, and the *Algæ* forthwith disappeared. This second aëration at the reservoir has been found necessary only during the warmest weather ; in fall, winter, and spring the water is artificially aërated only at the pumping-station.

The water of the Greenwood Cemetery Water Works, Brooklyn, New York, in the summer of 1885, became nauseous from the accumulation of a greenish vegetable slime. Examination revealed the fact that the water was deficient in dissolved oxygen, and that it contained an unusual number of *Diatoms*. The problem of purification was, therefore, to devise a process that would remove the pabulum necessary for their growth. An amount of air equal to one-tenth of the water, under a pressure of eighty pounds per square inch, was found sufficient to oxidize the pabulum, and the water was thus rendered clear and sparkling.

Under great pressure air rapidly oxidizes dead nitrog-

enous substances to inorganic products, and it therefore deprives the minute forms of life of the pabulum on which they thrive, and they are rendered latent. But it must not be understood that mere aëration effects these transformations, for the biological agencies are also important factors in assisting purification by the aëration of water. Oxidation is, indeed, but a finishing process, and, therefore, after coagulating and filtering out the bulk of impurities, a vigorous aëration, under high pressure, in such a manner as to cause the oxygen to reach every portion of the water, should be effected, and the oxidation completed there as far as possible. The excessive air should then pass to the filtering-beds, and in its slow passage through them assist in the separation and removal of the organic impurities. From such a system, water would emerge from the pipes highly charged with air, clear, sparkling, and as wholesome as the best standard of nature's purified springs.

Sedimentation.—In this country the water for city supplies is often partially purified by a process of sedimentation. This process is frequently used for the waters of the Mississippi and Missouri Rivers. The water is allowed to remain at rest for many hours in large, shallow settling-basins, in which the suspended inorganic matter subsides and thus mechanically removes also much of its organic matter. After subsidence of the impurities, the water is drawn off through a wire screen to retain fish and other large objects swimming in the water, and at regular intervals the sediment is removed from the basins. Owing to the expense of constructing, maintaining, and operating settling-basins, their use is not more extended. Other

systems of greater sanitary merit do the work of purification more beautifully and to the satisfaction and delight of the water consumers.

The sediment in the Missouri River at St. Louis, at certain seasons of the year, amounts to one and eight-tenths per cent of the bulk of the water. About ninety-four and five-tenths¹ per cent of this sediment is deposited in the settling-basins in twenty-four hours, during ordinary stages of the river; but for two months in the spring of each year, no convenient length of time for settling will clarify the water. When the water contains finely divided particles of clay, then the subsidence is so slow that for purifying purposes this process is a failure, and the softer the water, the slower the sedimentation. It is said that the fine argillaceous matter in the river Rhone requires four months of undisturbed repose for its subsidence. Time is, therefore, an important element in the purification of water by this process. But if the water is contaminated with sewage, or with the decomposition products of vegetable and animal matter, the sooner it is used, the less harm it will generally do. "To detain it in a settling-basin, especially in summer, long enough for even its suspended mineral matter to go to the bottom, is to brew a sort of devil's broth out of the putrescent ingredients, that will grow more poisonous every day it is kept."²

Dr. Percy F. Frankland³ has found that the twenty thousand germs per cubic centimetre, in the Thames River water, are reduced to about four hundred, by sub-

¹ *Engineering News*, 1881, p. 142.

² *Water*, Moore, p. 72.

³ Report of Maine State Board of Health, 1887, p. 316.

jecting the water to sedimentation and filtration; but from ninety-five and five-tenths to ninety-eight and nine-tenths per cent of the micro-organisms in the London water supply are claimed to be removed by filtration alone.¹

There are certain advantages derived from storing water, after sedimentation and filtration, in open reservoirs. This allows a free access of air for aëration, and the chemical rays of the sun to assist in decomposing the dissolvent organic matter of the water. In such cases a portion of the organic matter generally subsides to the bottom of the settling-basins; and the water, if previously colored, becomes more nearly transparent. But *more* and *greater advantages* are generally gained by storage in *covered reservoirs*, for the growth of *Algæ* and other micro-organisms is prevented, or at least retarded, by the absence of sunlight, and the covering also prevents an undesirable rise in temperature of the water. It is almost the universal practice with British and Continental water supplies of vaulting over the distributing reservoirs that are near the cities. When coverings are used, they should be so constructed as to allow a free circulation of the air in the reservoir. It is better still to have air pumped into the water impounded in these reservoirs.

Precipitation.—Many substances have been found useful in precipitating the impurities from water. Among those that have been mentioned are carbon, borax, ferric chloride, potassium permanganate, alum, calcium hydrate, and sodium carbonate. The choice of a sub-

¹ Report on Water Supply of East Saginaw, Michigan, p. 4.

stance depends upon the nature of the impurities, the use to be made of the water, and the magnitude and expense of the purifying system. A few points concerning some of these substances will suffice.

Ferric chloride,¹ to the amount of two and one-half, or three grains per gallon of water, has been used successfully in Holland in removing argillaceous and finely divided organic matter from the water of the river Maas, in furnishing the domestic supply for the city of Rotterdam.² Ferric chloride is a powerful oxidizing agent; and when followed by a solution of sodium carbonate, it gives excellent results, as the carbonate precipitates the iron, which entangles and removes the organic matter.

Potassium permanganate (in solution as Condyl's red fluid) is an excellent purifying agent, as it partially destroys organic substances by oxidation; and its manganese is generally precipitated as the hydrated sesquioxide, carrying with it much of the suspended matter present. A yellowish tint is sometimes produced in the water by the finely divided particles of oxide of manganese; and although this may be objectionable to the sense of sight, it has perhaps no ill effects upon the human system. This reagent readily removes any offensive odor from water, but the degree of oxidation of the organic matter depends somewhat upon the structure of the organic matter and the temperature of the water. Potassium permanganate is not a complete purifier of water, but it effects a change which alum cannot.

¹ *Water*, Moore, p. 76.

² *Water Supply Engineering*, Fanning, p. 533.

Alum has been used for centuries in China and India to purify water. Arago even observed its powerful action in the purification of the muddy water of the Seine. This reagent is especially efficient with waters containing calcium bicarbonate, and it clarifies them by precipitating the calcareous and argillaceous impurities; and in their removal it is itself precipitated as calcium sulphate and aluminium hydrate, which coagulates and removes the albuminous matter. So perfect is its self-precipitation that rarely can we find a trace of alum in the filtered water. Professor Leeds has shown that alum has also the remarkable property of removing *Bacteria* from water. He found that fifteen drops of the water from Mount Holly, when injected into a proper culture medium, produced eight thousand one hundred colonies of *Bacteria*, and that one-half grain of alum to the gallon of water reduced this number to eighty colonies. This is the coagulant used in the National, the American, the Hyatt, and some other systems of purification. The amount of alum used is from one-half to six grains per gallon of water. Alum can be obtained for one and one-half to two cents per pound, so its use under the most unfavorable circumstances is very inexpensive.

Clark's process¹ for softening hard water, by precipitating its lime as a normal carbonate, has been successfully used in several English water supplies, and also for private consumers. This is accomplished by adding to the water, in settling-basins, a sufficient quantity of *calcium hydrate*, in solution, to neutralize completely

¹ *Water Supply*, Nichols, pp. 183-186.

the carbonic acid, and thus precipitate all the lime as a normal carbonate. This carbonate mechanically precipitates clayey substances, and effects a nearly complete removal of the coagulated, gelatinous, and albuminous matter, as well as a complete removal of the coloring matter. Professor Edward Frankland has shown that Clark's process is very efficient in removing living organisms from water. The completion of the removal of lime is determined by means of a solution of silver nitrate. So long as the bicarbonates remain in solution the silver nitrate gives a white precipitate of argentic carbonate with the water; but so soon as the bicarbonates are removed, a brownish precipitate of argentic hydrate is formed. The objections offered against this system are, that if organic matter is present in large quantity, the chalk will not readily precipitate; the expense of constructing settling-basins is very great; and the accumulated chalk needs frequent removal from the basins, and consequently entails much expense. A modern improvement in this process, known as the Porter-Clark process,¹ consists in a remarkably rapid separation of the precipitate by means of a filter-press, which obviates the difficulty of sedimentation, and dispenses with the expensive settling-basins.

"Maiguen's and Howatson's processes aim at removing from the water the salts producing permanent hardness as well as chalk. In Howatson's process, a solution of caustic soda is mixed with the water to be softened, in addition to slaked lime. The precipitated salts are

¹ See *The Porter-Clark Process for the Softening, Purification, and Filtration of Hard Waters*, by John Henderson Porter, London.

removed by settlement as the water passes through a series of tanks. How much of the permanent hardness is reduced by these processes we have no means of knowing."¹

Sodium carbonate, or *sal soda*, is frequently used in softening water for the laundry, as it precipitates both the *temporary* and *permanent hardening bases* as *normal carbonates* ;² but this method is impracticable on a large scale.

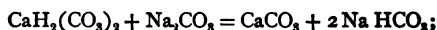
There are great economic advantages in using soft water. The beautiful water from Loch Katrine, having only one degree of hardness, in 1859 replaced the polluted hard water of the river Clyde, and has been of very great advantage to the city of Glasgow, which it supplies. This water has raised the standard of health of the citizens, and has been an enormous saving in manufacturing and industrial pursuits. The saving in the use of soap alone is estimated at thirty-six thousand sovereigns per annum.

Filtration. — The purification of water by filtration for city supplies has become quite general in Europe, and systematic filtering systems are now being introduced in many parts of the United States.

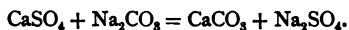
The essential object attained in the filtration of water is the removal of suspended mineral matter, together with the organic pabulum, or infectious matter, on which

¹ *Hygiene and Public Health*, Parkes, second edition, p. 56.

² With *temporary hardening salts*, the reaction is



and with *permanent hardening salts*, the reaction is



disease germs multiply and develop. Experience shows that this is best effected by first coagulating part of the organic substances, and filtering them out with the suspended matter, and then complete their removal by rapid oxidation under high pressure. Organic matter is sometimes removed by decomposing it with iron or other reagents, and the disagreeable gases arising from it are likewise removed. A large per cent of *Bacteria* is sometimes removed in filtering, and the remaining few are rendered latent for want of sustenance, and the water thus becomes harmless and palatable.

If, in addition to domestic purposes, the water is used in boilers, the injurious inorganic salts in solution should also be removed by precipitation, before filtration. And for city supplies, where the water is used necessarily for diverse purposes, a combination of chemical precipitation, filtration, and aëration is generally adopted by the filtering companies. In the subsidence of the inorganic salts, formed by the reagents used, much of the organic matter is also mechanically removed; and with a proper filtration for clarification, and a thorough aëration of the water afterward, the most perfect results are obtained.

It may be laid down as a general rule that while no water is injured by filtration through a proper medium, and under proper conditions, nearly all natural waters may be improved by the process. "While the benefits arising from the filtration of water have been proved by many satisfactory experiments and experiences, the chemical or mechanical changes which it undergoes are not well understood. By some, the changes which it undergoes are said to be due to oxidation; that is, to a

chemical combination of the impurity with oxygen from the air, by which the original is destroyed and some new and harmless one is produced. Every chemist knows that substances which are porous, or in fine grains, have the power of attracting air or oxygen to their surfaces, and, in the case of the porous substances, the amount absorbed is equal to a great many times the volume of the porous substance itself. This is notably true of animal charcoal, but it is very observable in sand or in fragments of glass. The organic matter in water, though it may be very active and dangerous, is in extremely small quantity, so that the amount of oxygen needed to consume it is very small. When the filters cease to act it is said to be because the oxygen on them is exhausted, and if they are taken out, cleaned, dried, and put in their places again, they act as efficiently as at first. This explanation is plausible, and, though not entirely demonstrated, it applies to the known facts more closely than any other. Numerous chemical examinations have been made of samples of water before and after filtration. They generally show a small diminution in the amount of organic matter, but not by any means sufficient to explain the changes which appear to have taken place in the properties of the water. The dangerous effects of organic matter in water are due not so much to its quantity as to its quality. It may well be that, in the process of filtration, its dangerous properties are to some extent destroyed, while the elements of its substance still remain. This explanation seems consistent, and may be accepted till some better one is found. The sanitary benefits of the filtration of water are so well sustained by experience that we must

advocate the adoption of plans for that end, whenever water that is liable to contamination is used.”¹

A filter should not only be capable of arresting suspended matter, but also all substances, in solution, which are physically or chemically dangerous; and it should so retain them that the water cannot wash them out during filtration. It should also be so constructed that it can be used for some time without deteriorating the quality of the water.

Filtration effects purification in four distinct ways:—

1. By straining, in which the efficiency and rapidity of the operation depends upon the size of the pores of the filter.

2. By adhesion of the impurities to the filtering substances, in which the efficiency depends upon the nature of the filters, and the relative surface of the filter-pores to the water filtered.

3. By sedimentation within the pores of the filter, and the efficiency here depends upon the size of the porous cavities and the rate of filtration.

4. By oxidation and other chemical action. The oxygen, condensed in the pores of the filtering medium, is very efficient in destroying organic matter, but it is rapidly removed in this process. In order, then, that a water may be successfully purified by filtration, the filtering medium should be frequently and thoroughly aerated. As the water falls from the filters it is also improved by aëration.

Professor Edward Frankland, of the Royal Commission of England, has thoroughly investigated the effi-

¹ Report of New Jersey State Board of Health, 1884, pp. 96-97.

ciency of the various methods of purifying water, and the following are the results of his observations upon filtration:¹—

1. A proper filtration may entirely deprive water of its living organisms.

2. By storing water in receptacles that are biologically unclean, living organisms may be introduced and rapidly multiplied.

3. Filters lose their efficiency by constant use, and instead of removing *Bacteria*, they finally increase the number of these organisms.

4. Some substances that manifest no chemical action on water are very successful agents in removing living organisms from it. Such are charcoal and coke.

5. The best results are attained when the filtering substances are frequently removed.

6. What is gained in rapidity of filtration is lost in its efficiency.

Sand is the material most frequently used for filter-beds, although brick, porous tiles, unglazed earthenware, sandstone,² carbonide of iron, spongy iron, compressed sponge, animal and wood charcoal, and coke have been suggested. Only few of these substances, however, can be relied upon for the removal and destruction of organic matter. Charcoal condenses oxygen in its pores, and as the water passes through it, the organic matter is

¹ *Journal of the Society of Chemical Industry*, December, 1885.

² "The Japanese use porous sandstone hollowed into the form of an egg, and set in a frame over a vessel, into which the water drops as it percolates through the stone. The Egyptians adopt the same method for clarifying the water of the Nile."—*American Cyclopaedia*, second edition, revised, p. 189.

rapidly and powerfully oxidized, and the foul gases are absorbed by it. But it is necessary that charcoal filters be frequently removed and exposed to the air, or sometimes reburnt, that they may remain efficient and absorb a fresh supply of oxygen, for a filter that is kept constantly in use soon becomes worthless. Filters should also be subjected to the influence of sunlight. British and Continental filter-beds are rarely roofed in.

Dr. Percy F. Frankland has found that powdered coke as a filtering material may completely remove micro-organisms from water; and Salamon and Matthews¹ have further shown that the action of coke is due mainly, if not entirely, to the presence of iron in it.

In constructing filters for cisterns, care should be taken to so arrange the parts of the filter that all organic matter possible may be removed, and that no color may appear in the water. For this purpose the conducting pipe from the roof should lead directly to the filtering-box, in which there should be layers of charcoal, gravel, and sand, of such a thickness as to effect this purification. The water should only flow into cisterns during the winter and spring months, when the atmosphere is clear and the rain nearly pure. Frequent removal and cleaning of filters are absolutely necessary; they should be removed at least once a year. A neglected filter is sometimes a source of danger, because use begets confidence and neglect. Under proper management a supply of pure, cold cistern-water may always be at hand.

Cisterns are sometimes constructed in two vertical

¹ *Journal of the Society of Chemical Industry*, 1885, p. 261.

compartments, separated from each other by a porous brick partition, laid in hydraulic mortar. The water is allowed to flow directly into one of the compartments, and filter through the brick wall into the other, from which it is drawn for use. At first, this is a very successful means of filtration, but the partition soon becomes charged with impurities, and finally does more for contamination than for purification. These filters are never aërated, and consequently they can have but a temporary oxidizing action on the impurities of the water.

No family should be without a private filter. Even the purest natural water can often be improved by its passage through a good filter, for there are substances that are sometimes mechanically removed, and chemical changes effected by this operation. But such filters must be properly cared for. There are many domestic filters in use, but some of them are of no benefit to the water. There is one class, however, that needs mention here, on account of its efficiency, from a biological standpoint.

Any filtering medium, like sand or uncompressed charcoal and coke, which has pores larger than one twenty-five thousandth of an inch in diameter, cannot successfully mechanically remove *Bacteria* from water. Pasteur¹ has, however, devised a sanitary filter which eminent authorities claim is germ-proof. The filtering material in this is a fine porcelain, imported from France. These filters, which are suitable only for domestic purposes, consist of two concentric tubes, the outer one

¹ See Reports of Pasteur-Chamberland Filter Company.

being connected with the water-pipe, and the inner tube is the porcelain filter. The water is admitted to the annular space between the two tubes; and it filters through into the central space, from which the clear, sparkling water is drawn. These filters are so constructed that they can be easily and daily cleansed. Other forms of sterilizing filters are in use, but space does not permit us to describe them here.

CHAPTER IX.

SYSTEMS FOR CENTRAL FILTRATION.

THE demand for pure water supplies in our towns and cities is one of the most important subjects with which our municipal authorities have to contend. People are now educated to the fact that a public water supply is an almost indispensable sanitary measure, and is essential to personal comfort and protection against fire. Sanitary science has forced upon water-supply companies the necessity of thoroughly clarifying and rendering wholesome the water that they furnish for use. Many of the sources from which water is taken are somewhat polluted, and the operation of purifying and furnishing it in the quantity needed for city use is often well-nigh insurmountable. Many methods of purification have been investigated; but the mechanical processes of filtration,¹ with or without previous treatment of the water, are the methods that naturally give the most perfect results. A few of these processes will now be described.

The Ground-water System.— One of the simplest and cheapest methods² of securing filtered water for city supplies is to sink wells or pits to a depth of ten to forty feet into the soil, near the bed of a river or lake, and

¹ *Filtration of Potable Water*, Nichols.

² *Water Supply*, Dickinson, pp. 10-11.

from these pump the water for general distribution. These wells are inclosed with iron or masonry walls, which prevent an influx of surface soil-water. The ground-, river-, or lake-water only enters them at the bottom; and it is thus subjected to filtration through natural soil. These wells generally receive a portion, at least, of their supply from the ground-water; and if this flows from underneath a densely populated city, it is liable to be impure. These wells are then like surface wells. But this system gives satisfactory results when the wells are sunk below an impervious stratum, for this separates the surface water of the city from the influx to the well; and these wells are pure, like those situated in deep subterranean strata. Wells should always be covered to prevent anything accidentally falling into them, and also to prevent the growth of *Algæ* through the agency of sunlight. They should be so arranged, however, as to allow a free supply of air into them. This system is in use at Des Moines, Iowa.

Instead of wells being sunk, "filtering galleries"¹ are often constructed deep in the soil, near a copious supply of fresh water, and from these the filtered water is pumped into the distributing-mains. The bottom and sides of the galleries are sometimes constructed of porous bricks, to allow the ground-water to enter, but more frequently only the bottom is of porous material. Such galleries are in use at Columbus, Ohio.

Long lines of collecting-pipes are also sometimes used for collecting the ground-water. They are cut with longitudinal slits, and put together with loose

¹ *Water Supply*, Nichols, pp. 107-109.

joints. The water that collects in these pipes is pumped to the distributing-mains. This method is in use at Dresden, Germany.

The location of a well or gallery near a river or lake is chosen because there is generally a movement of the ground-water toward the river or lake, and because in case of a great draught of water the other source may furnish the needed supply, if put in connection with the great pumps. "Bordering upon all rivers there are found at intervals narrow plains of gravel and sand, brought down and deposited there by the river under the varying positions of its channel way. When these beds of gravel extend to a depth below the bottom of the neighboring stream, they will always be found saturated with water mainly derived from that stream; and however turbid the water of the river, this underground flow will always be found clear, provided that we tap it at a reasonable distance from the channel way."¹

While in some cases the water of this system may come directly through the soil from the river, generally this is not the case. The beds of most rivers are quite impervious to water; and they, like artificial filters, soon become clogged, and pollute the water passing through them. And in most cases where the supply of water is dependent upon the river channel, the sanitary results are very unsatisfactory. It is never safe to rely upon the channel of the stream as representing that of the well. In some cases it may be the same, but in many it is very different.²

¹ *Filtration of Water*, Kirkwood, p. 17.

² *Water Supply*, Nichols, p. 124.

The Filter-bed System.—In the filter-bed system¹ the basins, as usually constructed, are from ten to sixteen feet in depth. Their size varies from twenty thousand to one hundred and fifty thousand square feet, and is determined by estimating that ninety gallons of water can be filtered per day through each square foot of surface. These basins are made water-tight by masonry, concrete, or puddled clay walls. In the bottom are radiating drains upon which is a layer of broken stone some two feet in thickness; then layers of coarse gravel, fine gravel, and finally the true filter, which is a layer of fine sand, from one to four feet in thickness. The water is kept from one to four feet in depth above the filters; and it is purified in its downward passage through the sand, and flows through the drains to a clear-water basin. The upper layer of sand does most of the work in intercepting the suspended matter in the water; but it does not do it all, under the conditions that occur in ordinary practice. The impurities are occasionally collected in the sand and gravel all the way through the filter-bed. When the filters become clogged, the water is drawn below the surface of the sand; and a layer of sand from one-half to three-fourths of an inch in thickness is removed, together with the débris which has accumulated on its surface. This practice is continued until the sand becomes too thin for efficient filtration, and then a new filter-bed is prepared. This system is especially applicable to the purification of river-water, but the sand acts only as a mechanical strainer. The

¹ *Water Supply of United States Capitol*, 49th Congress, Ex. Doc., No. 154, pp. 13-15.

sand has practically no effect in removing the dissolved mineral matter, unless there is a chemical change produced, through the flow of the water. Sometimes temporarily hard waters deposit a portion of their lime in the filter-beds, owing to the escape of carbonic anhydride. If the filter-bed contains soluble compounds, the filtered water may contain more salts in solution than the unfiltered water; but generally the amount is about the same in each. Poughkeepsie and Hudson, New York, use this system for purifying the water of the Hudson River; and the five water supply companies for the city of London, after impounding the water of the river Thames in settling-basins, further purify it by this system of filtration.¹

The Bischof System.—In 1871 Professor Bischof patented in England a process for the purification of water by filtering it through spongy iron. This preparation was found to remove successfully organic matter from water, and thus render it wholesome. But it was found that if the water contained a large amount of fine sand or mud, a preparatory filtration was necessary, and if there was also a large amount of salts in solution, then the water was liable to be impregnated with salts of iron derived from the filter-beds.

This system was, in 1881, put in operation at Antwerp, for purifying the muddy water of the river Nethe, and it remained in use till 1885, when it was superseded by the Anderson system. The polluted water was by this process rendered clear, colorless, and palatable, and the purification was more perfect than that by the An-

¹ *Hygiene and Public Health*, Parkes, second edition, pp. 15-17.

derson system ; but the rusting of the iron rendered the filtration slower and slower, until it became necessary to adopt a more rapid process. Professor Bischof claimed, however, that by the use of good, spongy iron, with proper management, this difficulty could be overcome.

For the city of Antwerp,¹ the water was taken from the river Nethe, about fifteen miles above the city, and was first impounded in two reservoirs, where it remained from twelve to twenty-four hours. From these reservoirs the water was pumped on the spongy iron filters, from which, by gravitation, it flowed to sand filters. The spongy iron filters were arranged on a bed of concrete, over which was placed two layers of bricks, loosely arranged. Upon the bricks was the filter, consisting of gravel mixed with one-third of its bulk of spongy iron. Upon this was a thin layer of gravel, and lastly, a stratum of fine sand, making in all a filtering material of five feet and three inches in depth. The sand-filters were likewise arranged on beds of concrete and bricks. They were composed of layers of gravel and sand, making a filtering material of three feet and nine inches in depth. The area of each filter amounted to seven thousand three hundred and two square feet, and the rate of filtration varied from sixty to one hundred imperial gallons per square foot of surface, in twenty-four hours.

The Anderson System. — Anderson's patent "Revolving Purifier" has been in use at Antwerp since 1885. This process consists in passing the water slowly through revolving iron cylinders, having inside projecting shelves.

¹ *Water Supply*, Nichols, pp. 166-168.

These cylinders are about two-thirds filled with iron borings, and are slowly revolved, so that some of the iron passes into solution as ferrous hydroxide. Every particle of the water passing through the cylinder is thus brought into direct contact with the iron, and the ferrous hydroxide successfully removes the odor from the water, and precipitates the organic matter, which is removed by filtering through sand; and in filtering, the ferrous salt is oxidized and removed. Professor Edward Frankland has shown that prolonged agitation with solid particles in the water completely destroys the living organisms in it; and the Anderson process, at Antwerp, completely sterilizes the water, and removes nearly all of its organic matter. The quantity of nitrogen is reduced to one-half or one-third the amount that the water originally furnished. At Antwerp, the time required for the water to pass through the cylinder is about three and one-half minutes, and for the completion of the purification, about six hours. This process, like the Bischof, requires a very expensive plant, and consequently has heretofore been but little used.

The Tweeddale System. — The Tweeddale system,¹ devised by Colonel William Tweeddale, of Topeka, Kansas, has proved very efficient on a small scale, and gives promise of great satisfaction for the purification of city water supplies. The lime in the water is precipitated, as in the Clark process; then a sufficient quantity of carbonate of iron is added, to render insoluble the organic matter. If the water is hard and clear, a small quantity of clay is then added. The water is then vio-

¹ Report of Kansas State Board of Health, 1887, pp. 330-331.

lently agitated by means of an air injector, after which it is allowed to stand for ten minutes, to complete the reaction. The water is again violently agitated from fifteen to twenty-five minutes, after which the impurities are allowed to settle, and the water is removed by decantation. The impurities must be frequently removed from the settling-tanks. The time required for the clarification by this process is from three to four hours. In this system, the water is softened, the organic matter is largely precipitated, and the remainder oxidized to inorganic salts, while the living organisms are mostly destroyed.

The National System.— This system,¹ like those that follow, claims to effect the purification of water by one or more of the three following methods: 1. By the use of proper precipitants, when needed; 2. by filtration through a clean filter-bed; and 3. by oxidation under high pressure, compressed air.

Precipitants are used for two purposes: 1. To soften the water; and 2. to remove color and silt.

The hardness is removed by injecting into the water, just before filtering, sufficient calcium hydrate to neutralize the dissolved carbonic acid, and then, if necessary, by adding sufficient soda to combine with the sulphuric acid of the sulphates present. Color and silt are removed by adding, before filtering, sufficient alum or ferric chloride to neutralize the alkaline reaction of natural waters. The alumina and oxide of iron thus precipitated are caught, together with these impurities, by the

¹ I am indebted to Professor A. R. Leeds, Ph.D., for the facts contained in this description.

filter-bed, none escaping into the filtered water. Less than a grain of the reagent per gallon is ordinarily used.

The peculiarities in the construction of the filters are two in number. The first provides for a system of *surface* washing. The great bulk of the impurities is caught on the surface of the filter-bed, and is removed by washing upward through a network of pipes placed just below the surface. The second peculiarity is a network of valves joining a part of the bottom of the filter-tank. The valves are made of a series of perforated pipes placed on the inside of larger perforated pipes, the space between being filled with coarser sand than that which forms the filter-bed. This coarse sand acting as a filtering medium, prevents the fine sand of the bed from passing out with the filtered water. When the entire bed needs cleaning, a reverse current is sent through these bottom valves, and all the sand, some four feet in depth, is washed simultaneously. The water used in washing is part of that already filtered, and amounts to two or three per cent of the latter.

Aëration is resorted to when the water is highly colored, or when it stagnates in the reservoir, or when it is desirable, after removing the dissolved carbonic acid, to render the water sparkling and palatable. It is effected either by forcing air by means of an air compressor into the water-main, just after the water leaves the pump, or through a series of pipes terminating in distributing noses, placed just above the bottom of the reservoir. Usually the first is sufficient, but when great trouble is experienced from the growth of plants in the reservoirs, both methods of aëration are used at the same time. Hoboken, New Jersey, uses both methods; Norfolk, Virginia, the first only.

The American System.—The American Filter Company¹ claim to use chemicals for purifying water according to local circumstances and conditions of the water, either through the suction pipe of the pump or through the supply main of the filter, in case there is no pump.

In this system there is used any filtering material or "bed" suited to the work to be done.

The theories upon which the filters are operated are,—

1. By delivering water to the bed of the filter, below the top surface, when this is clogged, is equivalent to beginning again with a clean surface.

2. The water used in washing must be applied directly to the accumulated impurities until they are removed, and then directly to each successive portion of the bed.

3. The most effective way of scouring off the accumulations is by the action of small jets, having great velocity.

To accomplish these objects, the water is delivered, both while filtering and washing, through eight radial arms, perforated with small holes. These arms, being connected to a piston-rod, can be lowered or raised at will. When the surface of the bed is clogged, they are depressed through it. When this part is clogged, they are again depressed, and so on until the whole capacity of the bed is exhausted, the filtration continuing the whole time.

During washing, the water outlet is closed, the sewer connection is opened, and the arms are moved up and down, twice each way, agitating the bed violently and cleansing it thoroughly. They are then stopped at the

¹ See Reports of this Company.

top, above the bed, the clear water outlet is opened, the sewer opening closed, and filtration begins again.

The operation of washing takes about five minutes, and the loss of water is about two per cent. Clean water can be used for washing from a tank supply when one filter only is used—or from the other filters, if more than one is used.

The process of aëration is generally accomplished by forcing the air into the main beyond the filter, by any of the common methods of compressing air, and it has not been found necessary to devise any special apparatus for this purpose.

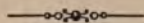
The Hyatt System.—In the Hyatt system¹ of purification, the inconvenience and difficulty attending the frequent removal of sediment and sand are also easily obviated, and the filters can be easily, cheaply, and thoroughly cleansed. The impurities are coagulated by means of alum, and the water then passes to the steel filtering-chamber, where they are removed. This is a vertical cylinder, having a diameter nearly twice its height. Through the middle is a horizontal diaphragm capable of withstanding the hydrostatic pressure necessary for rapid filtration. The lower section of the cylinder is filled with the filtering material, which consists of two parts of coke and three parts of sand. The upper part of the cylinder is used for washing the filtering material, which is transferred to it at regular intervals in a state of violent agitation, by hydraulic currents, and the impurities flow away through pipes situated

¹ For history of the Hyatt system, see *Scientific American Supplement*, October 10, 1880.

near the surface. The water is admitted through pipes to the upper part of the lower section of the cylinder, and it is drawn out through perforated cups that admit the water, but exclude the sand. The efficiency of this system depends more upon the successful precipitation and entanglement of germ life by the coagulent used than upon the merits of the filter. Aërating systems are also attached to large filtering-plants, and are said to give excellent results. The Hyatt system is not only one of the most popular for central purification, but is also successfully used for private supplies.

Regarding the comparative efficiency of the foregoing systems of purification, the author desires only to say that each is unquestionably excellent for certain kinds of water, and each has its advocates among scientific investigators.

APPENDIX.



SECTION A.

THE ORIGIN AND HOME OF CHOLERA.

THE following graphic description of the origin and home of Asiatic cholera, from the pen of Dr. D. B. Simmons, Chairman of the Yokohama Foreign Board of Health, will be of interest here:—

“The drinking-water supply (of India) is derived from wells, so-called ‘tanks,’ or artificial ponds, the water-courses of the country. The wells generally resemble those in other parts of Asia. The tanks are excavations, made for the purpose of collecting the surface water during the rainy season and storing it up for the dry. Necessarily they are mere stagnant pools. The water is used not only to quench thirst, but is said to be drank as a sacred duty. At the same time, the reservoir serves as a large washing-tub for clothes, no matter how dirty or in what soiled, and for personal bathing and ablution. Many of the water-courses are sacred, notably the Ganges, a river sixteen hundred miles long, in whose waters it is the religious duty for millions, not only of those living near its banks, but of pilgrims, to bathe and to cast their dead. The Hindoo cannot be made to use a latrine. In the cities he digs a hole in

his habitation ; in the country he seeks the fields, the hillsides, the banks of streams and rivers, when obliged to obey the calls of nature. Hence it is that the vicinity of towns and the banks of the tanks and water-courses are reeking with filth of the worst description, which is of necessity washed into the public water supply with every rainfall. Add to this the misery of pilgrims, their poverty and disease, and their terrible crowding into the numerous towns which contain some temple or shrine, the object of their devotion, and we can see how India has become and remains the hotbed of the cholera epidemic. In the United States official report, the horrors incident upon the pilgrimages are detailed with appalling minuteness. W. W. Hunter, in his *Orissa*, states that twenty-four high festivals take place annually at Juggernaut. At one of them, about Easter, forty thousand persons indulge in hemp and hasheesh to a shocking degree. For weeks before the car festival in June and July, pilgrims come trooping in by thousands every day. They are fed by the temple cooks to the number of ninety thousand. Over one hundred thousand men and women, many of them unaccustomed to work or exposure, tug and strain at the car until they drop exhausted, and block the road with their bodies. During every month of the year a stream of devotees flows along the great Orissa road from Calcutta, and every village for three hundred miles has its pilgrim encampments. The people travel in small bands, which at the time of the great feasts actually touch each other. Five-sixths of the whole are females ; and ninety-five per cent travel on foot, many of them marching hundreds and even thousands of miles, a contingent having been drummed

up from every town or village in India by one or other of the three thousand emissaries of the temple, who scour the country in all directions in search of dupes. When those pilgrims who have not died on the road arrive at their journey's end, emaciated, with feet bound up in rags and plastered with blood and dirt, they rush into the sacred tanks or the sea, and emerge to dress in clean garments. Disease and death make havoc with them during their stay. Corpses are buried in holes scooped in the sand; and the hillocks are covered with bones and skulls, washed from their shallow graves by the tropical rains. The temple kitchen has the monopoly of cooking for the multitude, and provides food which, if fresh, is not unwholesome. Unhappily, it is presented before Juggernaut, so becoming too sacred for the minutest portion to be thrown away. Under the influence of the heat it soon undergoes putrefactive fermentation; and in forty-eight hours much of it is a loathsome mass, unfit for human food. Yet it forms the chief sustenance of the pilgrims, and is the sole nourishment of thousands of beggars. Some one eats it to the very last grain. Injurious to the robust, it is deadly to the weak and wayworn, at least half of whom reach the place, suffering under some form of bowel complaint. Badly as they are fed, the poor wretches are worse lodged. Those who have the temporary shelter of four walls are housed in hovels built upon mud platforms about four feet high, in the centre of each of which is the hole which receives the ordure of the household, and around which the inmates eat and sleep. The platforms are covered with small cells without any windows or other apertures for ventilation; and in these

caves the pilgrims are packed, in a country where, during seven months out of the twelve, the thermometer marks from eighty-five to one hundred degrees Fahrenheit. Hunter says that the scenes of agony and suffocation enacted in these hideous dens baffle description. In some of the best of them, thirteen feet long by ten broad and six and a half high, as many as eighty persons pass the night. It is not, then, surprising to learn that the stench is overpowering, and the heat like that of an oven. Of three hundred thousand who visit Juggernaut in one season, ninety thousand are often packed together for a week in five thousand of these lodgings. In certain seasons, however, the devotees can and do sleep in the open air, camping out in regiments and battalions, covered only with the same meagre cotton garment that clothes them by day. The heavy dews are unhealthy enough; but the great festival falls at the beginning of the rains, when the water tumbles in solid sheets. Then lanes and alleys are converted into torrents or stinking canals, and the pilgrims are driven into the vile tenements. Cholera invariably breaks out. Living and dead are huddled together. In the numerous so-called corpse fields around the town as many as forty or fifty bodies are seen at a time; and vultures sit, and dogs lounge lazily about, gorged with human flesh. In fact, there is no end to the recurrence of incidents of misery and humiliation, the horrors of which, says the bishop of Calcutta, are unutterable, but which are eclipsed by those of the return journey. Plundered by priests, fleeced by landlords, the surviving victims reel homeward, staggering under their burdens of putrid food wrapped up in dirty clothes, or packed in heavy baskets

or earthenware jars. Every stream is flooded, and the travellers have often to sit for days in the rain on the bank of a river before a boat will venture to cross. At all these points the corpses lie thickly strewn around (an English traveller counted forty close to one ferry), which accounts for the prevalence of cholera on the banks of brooks, streams, and rivers. Some poor creatures drop and die by the way; others crowd into the villages and halting-places on the road, where those who gain admittance cram the lodging-places to overflowing; and thousands pass the night in the streets, and find no cover from the drenching storms. Groups are huddled under the trees; long lines are stretched among the carts and bullocks on the roadside, their hair saturated with the mud on which they lie; hundreds sit on the wet grass, not daring to lie down, and rocking themselves to a monotonous chant through the long hours of the dreary night. It is impossible to compute the slaughter of this one pilgrimage. Bishop Wilson estimates it at not less than fifty thousand. And this description might be used for all the great Indian pilgrimages, of which there are probably a dozen annually, to say nothing of the hundreds of smaller shrines scattered through the peninsula, each of which attracts its minor hordes of credulous votaries. So that cholera has abundant opportunities for spreading over the whole of Hindoostan every year by many huge armies of filthy pilgrims, and the country itself well deserves the reputation it universally possesses of being the birthplace and settled home of the malady."¹

¹ This description was republished in Report of Michigan State Board of Health, 1885, pp. 62-64.

SECTION B.

QUALITATIVE TESTS FOR IMPURITIES IN DRINKING-WATER.

I. CHEMICAL TESTS.

The Permanganate Test.¹—Potassium permanganate is often used to detect the presence of decomposing organic matter in water. The experiment may be conducted as follows: to a litre flask, nearly filled with the water under consideration, add enough potassium permanganate, in solution, to give a faint purple color to the water. Then add a few drops of dilute sulphuric acid to render the water slightly acid, shake well, and allow the solution to remain in a moderately warm place for one hour. If, in this time, the purple color disappears, or is reduced in intensity, with the development of a brownish color instead, decomposing organic matter is *generally* present. The fading of the color of the permanganate solution is, in this case, caused by the oxidation to water and carbonic anhydride, of the hydrogen and carbon of the organic matter; and a *rapid decolorization* of the solution usually indicates further, that the reducing agent is *animal* matter. But this should not be considered an infallible test of a danger-

¹ This is also known as the Forchammer test, and was originally proposed in 1850, by Professor G. Forchammer, of Copenhagen.

ous impurity, since there may be present in the water other reducing agents, as ferrous salts, nitrites, and hydrogen sulphide, which are capable of producing this change in the color. This test has often proved fallacious in the hands of beginners; it can be considered reliable only in the hands of experts. A water which contains an appreciable amount of decomposing organic matter should not be used for domestic purposes, without first being boiled.

The Argentic Nitrate Test.¹—Argentic nitrate gives with the soluble chlorides a white precipitate of argentic chloride, which is readily soluble in ammonium hydrate, but insoluble in dilute acids. The presence of an excess of chlorine in water can, therefore, be determined as follows: use two beakers, each of about one hundred cubic centimetres capacity. Into one put the water to be tested, and into the other, a sample of ground-water of known purity, from the vicinity. Add to each a few drops of chemically pure nitric acid to insure acidity of the waters, and then a few drops of a solution of argentic nitrate. The water in which there is produced the greater turbidity contains the larger amount of chlorine. All natural waters contain soluble chlorides, and the amount varies with the composition of the soil, proximity to the sea, or contamination of the water with sewage. The amount of chlorine in a well-water should not be widely different from the average amount in pure ground-water found in the neighborhood of the well. The small amount of chlorine found in drinking-water is not, in itself, injurious to the human system; but if

¹ Report of National Board of Health, 1880, pp. 479-482.

in excess, it indicates a probable contamination of the water with sewage. Human urine contains about five thousand milligrammes of chlorine per litre, and when this has access to the soil, as it has from many privies, the well-waters in the vicinity are often contaminated with it, which contamination is easily recognizable by the increase in the amount of chlorine. Pure well-water does not often contain more than twenty-three milligrammes of chlorine per litre. And whenever the water examined contains considerable more chlorine than does the average ground-water of known purity in the vicinity, it should not be used until further examined by a competent chemist.

II. BIOLOGICAL TESTS.

Heisch's Sugar Test.¹—This biological test, so frequently used, depends upon the fact that if sugar is added to water containing a mere trace of sewage, the *sewage fungus*, or *Beggiatoa alba*, will appear. The test may be made as follows: Into a clean eight-ounce bottle, with ground-glass stopper, introduce about one gramme of pure, granulated sugar, and then fill the bottle with the water to be tested. After the sugar has dissolved, set the bottle in a warm place, where sunlight can have daily access to it, and allow it to remain there at least forty-eight hours. Examine the contents of the bottle occasionally, to determine the rapidity of development in cloudiness of the liquid, and the odor evolved. If the *Beggiatoa alba* is present, which *Alga* multiplies

¹ *Sanitary Examination of Water, Air, and Food*, Fox, pp. 24-25; also, *Foods: their Composition and Analysis*, Blythe, p. 546.

rapidly in saccharine solutions, a milkiness will be produced, and the water will evolve the odor of butyric acid. At first, small cells, with bright nuclei, appear, which in a few hours change to maniform threads, and finally to cells mixed with mycelium. While all waters that are contaminated with sewage will develop this cloudiness, Dr. Frankland has shown that this change is not an infallible test of sewage, since other kinds of organic matter will produce like results. The cloudy matter developed by the sugar should be examined microscopically, to determine the kinds of *Algæ* present. A water that gives this sewage test should never be used for drinking.

The Microzyme, or Bacteria, Test. — Prepare Pasteur's solution as follows: Dissolve ten grammes of granulated sugar, five grammes of ammonium tartrate, and one-tenth of a gramme of well-burnt yeast ash, in one hundred cubic centimetres of distilled water. This solution should be clear. It is an excellent culture medium for *Bacteria*. Insert about two cubic centimetres of this solution, after it has been boiled, into a sterilized test-tube (heated to one hundred and eighty degrees Centigrade); then pour three or four drops of the water to be tested into the solution, and immediately fill the open end of the tube with cotton wool. If *Bacteria* are present they will, in a few days, produce an opacity in this culture medium. As all natural waters¹ contain these micro-organisms, no unchangeable basis can exist for a comparative biological examination of their qualities.

¹ Distilled water and water which has been boiled for several hours may be free from *Bacteria*.

The relative amount of organic impurity contained in a water can be judged in this experiment only by the degree of opacity of the culture medium, and the rapidity of its development. This is an important test for impurity, for a large number of rapidly developed micro-organisms in water necessarily indicates the co-existence of a large amount of decomposing organic matter.

The most thorough investigations of water supplies that have been made in this country during the last two years are perhaps under the direction of the Massachusetts State Board of Health. The first published report of these examinations is already at hand, and contains discussions on the chemical, microscopical, and biological examination of water; the influence of biological agencies in the purification of water; the pollution and the self-purification of streams; the influence of storage on the quality of water, etc. This report is a very valuable contribution to sanitary science, and should be in every chemist's library.

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